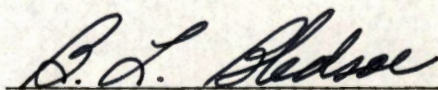


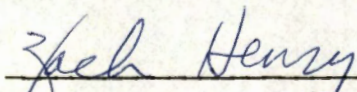
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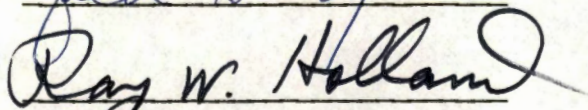
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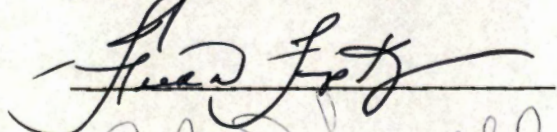


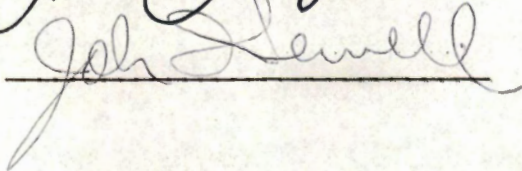
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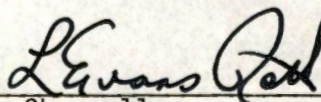








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DESIGN, CONSTRUCTION, AND EVALUATION OF A CONTINUOUS BAND CUTTING
MECHANISM FOR REDUCING SHATTER IN SOYBEANS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Joel Thomas Walker

March 1979

1280199

This work is dedicated to Freda and Benjamin, my family.

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ABSTRACT

A large quantity of soybeans have been lost each year due to shatter caused by the cutterbar and other combine header components. A band blade cutting device was designed, constructed, and tested for effectiveness in reducing these shatter losses. The electrically driven band ran in a rectangular path around four 20.3 cm (8.0 in) diameter wheels. The blade thickness was limited to 0.05 cm (0.020 in) or less due to the stresses induced when traveling around the wheels. The blade return path precluded the use of a conventional reel. A reel having bats carried by chains was devised. The new header was attached to and powered by a Chain Machine Company SP-50 plot combine.

Laboratory tests were performed in which a plant carriage system was used to feed erect plants into the stationary headers of both the conventional and the experimental machine. An abrasive "Grit-edge" blade was used. The band-blade header was compared to the conventional cutterbar header on the bases of percent shatter loss, uncut (lodged and stubble) loss and total loss. Four levels of band blade speed between 460 and 910 m/min (1500 and 3000 ft/min) were used. Simulated ground speeds were set at four levels between 3.2 and 6.4 km/hr (2 and 4 mi/hr) while testing the band blade header. The conventional header was tested at 330 cycles/min and a simulated ground speed of 6.4 km/hr (4 mi/hr). Response surfaces of shatter, uncut, and total losses as a function of blade speed and ground speed of the band blade header were

developed. Blade speeds of 910 m/min (3000 ft/min) reduced shatter below the levels found in the conventional header for all ground speeds. However, the uncut and total losses were not lower for the band blade header.

Five high speed cinema films were taken as part of the laboratory tests. The author concluded from the shatter tests and film studies that the abrasive blade did not cut rapidly enough. The abrasive surface did not positively engage the plant fibers. A high force normal to the cutting edge was required to aid the cutting action. The plants were excessively disturbed.

A toothed blade was selected for field tests after consideration of the laboratory results. A spring steel blade having a tooth pitch of 5.1 mm (5 teeth per inch) was selected. Shatter, stalk, lodged, and stubble losses were collected from a 137- x 91-cm (54- x 36-in) area after the combine header had passed. Five blade speeds between 610 and 1830 m/min (2000 and 6000 ft/min) were used. Ground speeds were set at five levels between 1.6 and 4.8 km/hr (1.0 and 3.0 mi/hr). Moisture and maturity of the beans were monitored. The field tests were not sensitive enough to measure all effects adequately due to insufficient replication. The linear component of ground speed was found to significantly effect shatter at the 90 percent level of probability. Comparison of means between the band-blade header and the conventional header showed that shatter, lodged, and total losses were not different, but stalk and stubble losses were lower for the band blade header. The cutting action was smooth. Little plant disturbance was observed during operation in the field.

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CHAPTER I

INTRODUCTION

The combine header initiates the grain harvesting operation by severing the crop stems. The conventional cutting process uses a reciprocating bar of knives acting against stationary shear surfaces or ledgers. This mechanism, however, causes more grain loss than any other combine element. To eliminate this grain loss, many different types of cutting mechanisms have been investigated with varying degrees of success, but a completely satisfactory cutting device has not yet evolved.

A. Design Goals for a Combine Header

A combine header must adapt to the specific needs of the crop. A general purpose header is desirable. The cutting element should be capable of cutting stalks close to the ground (Byg, 1970) to minimize stubble losses (Quick, 1974). Ground contours should be followed. Impact and vibration of plants that cause grain shatter should be minimized. Sufficient capacity is necessary for timely harvest and efficient utilization of subsequent combine components.

Crops vary widely in harvesting characteristics. Crop variety, stem size, stem length, yield, moisture content, and soil conditions can all affect the losses at the header. Narrow row or broadcast crops may be desirable. Therefore, a header which will harvest them is needed.

The reel and guide structures also have an effect on grain losses. The reel should be designed and operated such that a minimum of agitation of the plants occurs. Components which guide the plants both before and after cutting should be designed for smooth flow of material to prevent shatter and clogging.

B. Inadequacies of Present Systems

The conventional reciprocating cutter has several disadvantages. The reciprocating motion inherently limits the speed of operation. Vibrations caused by the oscillation induce shatter of the grain and cause extra loading of structural machine components. A substantial amount of energy is required to keep the blade in motion even when not cutting. The knife motion causes a shaking of the plant stem which results in further shatter losses. Present reel designs are such that excessive shatter occurs due to direct impact and plant agitation.

A band cutting device could offer some advantages over a reciprocating blade in harvesting seed crops. A continuous cutting surface should sever the plant quickly, with a minimum of disturbance. Vibrations of structural members should not be a problem. With continuous, unidirectional motion the band blade might require less energy to operate than a reciprocating device which has cyclic accelerating-decelerating loads.

C. Research Objectives

This study proposed to determine the feasibility of using a continuous band blade cutting device in the harvest of soybeans

with a combine. Specific objectives were:

1. To design and construct a continuous band cutting system, supporting framework, and header components for use with the Chain Machine Company SP-50 plot combine.
2. To evaluate the experimental device in laboratory and field tests, determining relative amounts of shatter loss as compared to the conventional SP-50 header. The effect of different combinations of ground speed and blade speed on shatter losses were to be observed.
3. To determine the power required to drive a practical band cutting system.

CHAPTER II

REVIEW OF LITERATURE

A. Introduction

The combine was designed primarily to harvest small grains rather than soybeans. Yet, in 1977, 60.5 million m³ (1.716 billion bu) of soybeans were harvested with combines in the United States (Doane's, 1978). It was shown (Quick, 1973) that an average of 9 percent of the total soybean crop was lost because the combine was not adapted to gentle handling of the soybean plant. This total loss then could have amounted to nearly 6 million m³ (170 million bu) in 1977 and probably represented a third of the farmer's potential profits (Quick, 1973).

B. Types and Causes of Losses

Gathering or header losses are classified into several distinct categories (Quick and Buchele, 1974). Shatter loss is defined as loose beans or pods not attached to the plant resulting from machine action. Shatter loss does not include those beans dehisced prior to harvesting. Stalk losses are pods connected to stalks which are cut but not gathered by the machine. Lodged losses occur when the machine fails to cut a stem containing pods and rides over it leaving stems longer than the normal stubble length. Stubble loss consists of pods attached to stems below the ordinary cutting height of the header.

Gathering losses are caused by a variety of header actions.

Shatter is caused mainly by the cutterbar. The initial impact of the blade on plant stems causes an acceleration of the pods which induces shatter. Plant stems may be thrust laterally as much as 8.1 cm (3.2 in) before being cut by the blade (Kepner, 1952). The oscillating motion of the blade causes vibrations in the stationary parts of the header which may induce shatter and subsequent loss of beans when the parts contact pods. The direct cutting of pods by the blade also causes loss of beans in the shatter category. Reel action may cause shatter by scraping or by direct impact (Lamp et al., 1962). Stalk losses may occur from expulsion of stems by the cutterbar, auger, or reel. Lodged plants may not be lifted enough by the reel to be fully cut by the blade. If the cutterbar is unable to cut close to the ground level and to follow ground irregularities, both stubble loss and lodged loss may increase.

Dunn et al. (1973) performed field tests to determine which header components contributed most to soybean loss. Three treatments were used to study the effects of the cutterbar, reel, and auger. The first treatment employed the cutterbar only. The second treatment utilized both cutterbar and reel. Finally, the complete header was used for a third treatment. A special carriage provided support and power to the mechanisms being tested. A roll of plastic film was deployed by the carriage to separate the cutterbar losses from the plant material passing over the cutterbar.

They tested three varieties in 76-cm (30-in) rows. Moisture content was near 12 percent. A ground speed of 4.5 km/hr (2.8 mi/hr) was used. Reel index (ratio of peripheral reel speed to ground speed) was

1.49 for treatments one and two and was 1.34 for the third treatment (complete header). Shatter loss, stubble loss, stalk loss, and lodged loss were observed in the three alternate zones between six rows. Pre-harvest losses were sampled prior to testing.

Their results indicated that the cutterbar caused 81.1 percent, the auger caused 13.1 percent, and the reel caused 5.8 percent, respectively, of the total header loss. Furthermore, the header loss components were shatter loss, 64.1 percent, stalk loss, 31.2 percent, stubble loss, 3.6 percent, and lodged loss, 1.1 percent. Cutterbar improvements which would reduce stubble height and stalk vibrations were recommended.

Quick (1973) performed laboratory tests to study header losses. He maintained that gains made in recent years by shatter resistant varieties and automatic controls have been offset by increased header widths and faster ground speeds. Reasons given for performing laboratory tests rather than field tests were reduced time and labor, reduced cost, smaller sample size with higher reliability, removal of the weather factor, better control over experimental conditions, better isolation of the causes of loss, and convenience in testing improvements to headers.

A wheeled carriage was used on a track to carry test material into the stationary header. Cutting height could be varied from 5 to 15 cm (2 to 6 in). The carriage was 1.5 m (5 ft) long. Rubber weather-strip was used inside the carriage clamp to reduce the crushing of stems and to provide a better grip on the plants. A standard test was conducted using a 1.2-m (4-ft) row segment of plants.

Plants to be tested were pulled from the field and shaken to remove dirt from roots. Plants were stored until needed, but moisture content was not strictly controlled. As the plants were being cut, losses were collected in troughs, and the collected material was threshed.

Quick made several observations from his tests. The crop moisture content was found to have a pronounced effect on shatter loss. Total header loss, shatter loss, and stalk loss all increased as moisture content decreased. Stubble loss dropped slightly at very low moisture. He found that total header loss reached a minimum when the reel index was near 1.78. This value was somewhat higher than the previously recommended 1.25 value. Faster reel speeds resulted in less loss than lower reel speeds. The reel height and its distance in front of the cutterbar also affected total header loss.

The auger speed had little effect on losses in the laboratory. However, with slow auger speeds, losses in the field were expected since cut material was not rapidly removed from the cutterbar area by the auger. Smooth flow of cut material from the header became more important at high ground speeds.

In the laboratory tests, the header loss minimized near 3.11 km/hr (1.93 mph). All categories of loss increased with increasing ground speed above 3.2 km/hr (2 mph). Also, shatter loss was greater at very low ground speeds. Losses at higher speeds were reportedly caused by stem crowding and plugging. Cutterbar speed had similar effects, with header and shatter losses reaching minimums near 400 rev/min (800 strokes/min).

Quick's results showed that of the total crop, 2 percent was lost before harvest. Nine percent of the total crop was lost due to the combine. Of combine losses, 84 percent was lost due to the header action, while the remaining 16 percent was due to other combine components. Header losses were subdivided into shatter loss, 61.2 percent; stalk loss, 21.0 percent; and stubble loss, 17.8 percent. Header losses were caused by the cutterbar, 79.6 percent; auger, 12.8 percent; and reel, 7.6 percent.

C. Causes of Shatter

Hoag (1972) performed experimental studies to determine the factors affecting shatter. He implied that plant breeders did not have an adequate means of determining the shatter resistance of soybeans when subjected to mechanical action. Hoag studied the energy absorbed by the pod as it shattered from impact and the impulse caused by the impact. He chose these variables because of the brittle failure which he claimed occurred during shatter.

Pods were dropped from increasing heights until shatter occurred. This procedure indicated an energy of 230 to 690 cm-gm (0.2 to 0.6 in-lb) was required to initiate shatter in individual pods. A special ballistic pendulum device was constructed to measure this small energy quantity. Single pods, supported from both ends, were struck in the center by a pendulum released from a predetermined height. The energy absorbed was determined from the horizontal component of the pendulum travel after striking the pod. Moisture content of the shattered pods and seeds was determined. Force was measured by a piezoelectric force transducer

mounted on the pendulum end and connected to appropriate instrumentation. Impulse was determined by integrating the force-time curve with planimeters.

Results showed that shatter energy increased with an increase in moisture content. Extreme (high or low) moisture content seemed to interact with impact velocity to affect energy absorption. The impulse was found to increase with increasing moisture content. However, this effect was less pronounced at higher impact velocities.

Hoag also used high speed photography to observe the shatter process during these experiments. The purpose was to determine if the kinetic energy of the soybeans was taken directly from the pendulum or gained from a recoverable shatter energy. He observed that transducer forces had disappeared before the beans appeared to move. He concluded that the beans gained kinetic energy from a recoverable portion of the shatter energy.

In continuing his study, Hoag (1974) included a "quasi-statically applied force" to cause pod failure. He developed an energy model in which the modulus of elasticity could vary with moisture content. The strain rate was suspected of affecting the apparent strength of the soybean pods. Also, the cyclic wetting and drying which occurs in the field was said to simulate fatigue loading. Older pods were suspected of having less strength. The rupture strength in the energy model was expected to be:

$$\sigma_r = A + BM + CM^2 + a_1 \ln D + a_2 \ln V$$

where

σ_r = rupture strength, psi,

M = moisture content, percent,

D = number of days after maturity,

V = impact velocity, in/sec, and

A, B, C, a_1 , a_2 = constants.

A force model was considered and had the same form as the energy model assuming pods had uniform geometry and force was applied similarly in all tests. An impact model was chosen and included polynomial terms for both energy change and velocity of the impact device.

Impact loading was performed as in the earlier experiment (1972) to test the impact model. The force and energy models were tested by applying a force with either a spring scale or Instron testing machine until shatter occurred. Field losses were measured by collection after a combine had backed away from a cut. Maturity dates were estimated and moisture contents were established for individual pods. A regression procedure correlated the predicted strength with actual field losses.

Hoag found that moisture content and maturity interact to affect soybean shatter. He suggested the inclusion of rainfall, temperature, and humidity data in further studies. The energy and force model regressions alone were not useful in predicting soybean losses in the field. The impulse model was a good indicator of field shatter losses.

Nave and Hoag (1974) took a different approach in studying shatter loss. Their purpose was to study the effects of guard spacing and sickle speed on shatter. A standard cutterbar was used in the sickle speed tests. A test stand provided support for the header. Sickle stroke was 7.6 cm (3 in). Frequencies of 500 (standard), 700, and 900 cpm were

used. A ground speed of 4.8 km/hr (3 mi/hr) was used. Moisture content was tested at 11 and 13 percent. Reel index was 1.5.

A simulated floating cutterbar was utilized in the guard spacing tests. Both 3.81- and 7.62-cm (1.5- and 3-in) spacings were used. Both were driven with a 7.62-cm (3-in) stroke). A 5.1-cm (2-in) stroke and spacing was also used with guards having no tops. The experimental methods described by Tunnell et al. (1973) were employed. For cutterbar configuration tests, sickle frequency was 500 cpm and moisture content was 11 percent. Some high speed movies were made to study plant acceleration.

Nave and Hoag concluded that higher sickle frequencies offered no advantage. Removing guard tops might significantly reduce shatter, they claimed, although stalk losses were greater. The plant acceleration caused by blade motion was said to be the cause of soybean shatter. Guard tops tended to cause a whiplash effect on the plants when the plants slammed against the tops and then sprang back. They claimed that a shorter sickle-guard spacing should reduce shatter by reducing plant acceleration. But they did not recommend the shorter spacings because of weed cutting problems.

Quick (1974) tested soybean plants and pods to determine "quantitative shatter index." This index was used to determine the propensity of soybean varieties to shatter under harvest conditions. Previously, natural field aging had been used by agronomists to observe the amount of shatter. He used vibration, impact, centrifugation, pod traction (tension) and compression to induce shatter by mechanical means. The effects of moisture content and variety were observed. Vibration

tests were performed with whole plants clamped by the stem in a horizontal position. An electro-mechanical shaker provided oscillation at a point 3.75 cm (1.48 in) from the clamp. Electro-optical tracking units and oscilloscopes were used to observe and record plant and shaker motion. The maximum stem acceleration was 280 g's at resonance. This acceleration was below the threshold for pod shatter. A few pods did shatter at frequencies near 45 Hz. Other frequencies produced no shatter. Individual pods were vibrated with the same shaker. Natural frequencies between 4 and 7 Hz were observed. Very few pods shattered. The vibration test was not continued due to its complexity.

Bifilar ballistic pendula were used to provide impact loading to individual pods. Impact velocity was 0.6 m/sec (118 ft/min). Piezoelectric force transducers and accelerometers monitored pod loading. Pods were loaded on the seams. The results were not clear. Tests were reportedly complex and expensive.

A centrifuge with pod ends clamped to its periphery, provided another form of loading. Shatter from the pods was recorded as the centrifuge speed was increased in increments of 100 rpm. Average forces up to 916 g's were obtained. Low moisture content was shown to allow more shatter. Most pods with low (8 to 10 percent) moisture contents were opened with less than 1.96-N (0.441-lb) force.

Tension tests were performed, pulling pods apart by aluminum foil tabs glued to their sides. An Instron tester provided a load rate of 1.0 cm/min (0.4 in/min) on pods at 10 percent moisture content. Load displacement curves were plotted which indicated the peak force occurred as the initial splitting failure occurred. Lower loads followed as tearing along the seams was observed.

Compression tests were conducted on the Instron tester. Compression loads were placed on the seams by a special anvil. Loading rate was 1.0 cm/min (0.4 in/min). The first load-deflection peak indicated the initial pod opening. This peak was called the "pod compressive shatter strength" and the inverse of the quantity was called the "compressive shatter index."

Compressive tests were easier to perform and gave more reliable results than the other tests. Therefore, it was recommended for further study. Moisture content was an important factor in the test results. Quick suspected that moisture content changes would affect the plant varieties differently. The loading rate was found to affect the results, also. Resistance to shatter decreased as load rate increased over the range of 0.5 to 50 cm/min (0.2 to 20 in/min). Cultural differences and late season shatter due to pod aging (called "cryptic" shatter by Quick) were also mentioned as possible causes for poor lab-to-field data correlation.

D. Reducing Losses

Various suggestions have been offered for reduction of soybean loss due to header action. Lamp et al. (1961) indicated four approaches for reduction of losses: "(a) development of plants better adapted to harvesting, (b) harvesting when losses are less likely to occur, (c) optimum machine operation, and (d) improved harvester design." Varietal development of improved pod height, shatter resistance, and lodging resistance has not had great success in reducing harvesting losses in recent years. Quick (1974) showed that early season harvesting when

moisture content is high reduced losses. Lamp et al. (1961) also indicated lower losses at higher moisture. However, it is not always possible to harvest under such conditions.

Optimum machine operation offers potential for substantial grain savings. Lamp et al. (1962) indicated that reel adjustments and ground speed were very important in their tests. They recommended a reel index of 1.25 with the reel bats penetrating no deeper than required to control the plants. Ground speeds near 3.2 to 4.8 km/hr (2 or 3 mi/hr) offered lower losses. At very low ground speeds the reel caused shattering. Ground speeds over 6.4 km/hr (4 mi/hr) caused high losses due to a cutter-bar stripping action. A wider range of adjustments to the header, threshing, and separating sections would reduce losses. These adjustments should be made as crop conditions change and might be too demanding even for an experienced operator to make as often as he should.

Perhaps the approach with the most promise to reduce losses was that of improving the harvester design. Lamp et al. (1961) recommended simplified adjustments and automatic controls. Other investigators have studied improvements or modifications to the header system. The literature was scattered with studies of modified sickles, air conveyors, reel mechanisms, rotary cutters, floating platforms and pullers which are meant to reduce losses.

Many attempts at improving the reciprocating sickle mechanism have been made. Harbage (1962) claimed that increased capacity could only be gained by increasing the length of the blade or by running the machine faster. Combine headers have been near practical width limits for some time. Byg et al. (1970) indicated that header losses had

increased with larger header sizes. Elfes (1954) developed a high speed sickle drive mechanism, and others have been developed in recent years. However, higher sickle blade speed did not improve the shatter loss in Nave and Hoag's (1974) experiment.

Nave et al. (1977) did further research toward reducing harvesting losses through the use of sickle modifications. In 1975 they tested conventional sickle and guards, conventional sickle and guards with tops removed, sickle and fixed shear bar, and a double sickle cutterbar in which both cutting surfaces reciprocated. In 1977, a conventional cutterbar was compared to a cutterbar having the normal 7.6-cm (3-in) stroke but with knife sections and guards spaced at 3.8 cm (1.5 in).

Plants were conditioned to 11 percent moisture content. Tests were performed in the laboratory on a test stand which simulated the action of a floating cutterbar. Cutterbar frequency was 500 cpm. Ground speed was 4.8 km/hr (3 mi/hr). A reel index of 1.5 was used. In 1977, the cutterbar having a short guard spacing was tested with conditions just mentioned and at a ground speed of 6.4 km/hr (4 mi/hr) and reel indexes of 1.0 and 1.5.

Both shatter loss and total header loss were found to be lower for the modified guard and double sickle arrangements than for the conventional and shear bar designs in 1975. Modified guards provided less shatter than did the double sickle. They found lower shatter losses resulted from lower plant accelerations in the modified guard and double sickle devices. The modified guards did not impact the plants above the knife as normal guards did. The double cutterbar caused less plant motion before cutting. In 1977 the narrow spaced cutterbar performed

well at reducing shatter and total header losses. Also the narrow spaced cutterbar worked well at higher ground speeds when the reel index was kept near 1.5.

Johnston (1959) observed the behavior of flax stems being cut by a double knife arrangement. He used 840 strokes/min and a cutting height of 3.8 cm (1.5 in). Feed rate was 5.1, 7.6, and 12.7 cm (2, 3, and 5 in)/stroke for the conventional cutter and 7.6, 12.7, and 22.9 cm (3, 5, and 9 in)/stroke for the double knife cutter. Ground speeds of 4.83, 7.24, 12.07, and 21.73 km/hr (3, 4, 5, 7, 5, and 13.5 mi/hr) were represented. The track mounted "crop" consisted of dry flax straws. Straws were 30.5-cm (12-in) long and were positioned in a 1.3-cm (0.5-in) square grid pattern.

A high speed camera and stereoscopic mirror arrangement were used to record the cutting process. The films indicated that plant slippage along the ledger or knife edge was not a problem. Disturbances in the stems were observed ahead of the conventional cutterbar and were attributed to knife motion being transmitted by the tops of stems. No disturbances were noted ahead of the double knife mower.

The bending of straws was also observed from the films. The tips of straws were seen to move very little during initial contact by the knife. The inertia of the stem presumably served to hold it still. However, the energy stored in the stems was released later by a whipping action of the tips. In grain crops this action should be avoided to prevent shatter. Straw tips were observed to have accelerations up to 200 g's. At this level the mass of the crop became very important.

A recent popular development which utilized the reciprocating sickle was the floating cutterhead. A conventional cutterbar was mounted on a structure which could more closely follow ground contours. This structure moved vertically relative to the rest of the header. A study of a short stroke sickle on a floating cutterhead was done by Quick and Mills (1976) in the hope that lower plant accelerations would reduce shatter. The guard and knife spacing of 3.81 cm (1.5 in) also promised shorter stubble length, therefore less stubble loss. Guards and knives were manufactured with multiple sections and were bolt-on type. The float mechanism was suspended by springs and could be adjusted for "float tension." The float mechanism could be locked if necessary. Height could be automatically or manually controlled.

Ground speeds of 4.8 and 9.7 km/hr (3 and 6 mi/hr) were studied. Both conventional and short stroke sickles were tested at 460 cpm. Close guard spacing was tested with strokes of 3.81, 7.62, and 11.43 cm (1.5, 3.0, and 4.5 in). Losses below 1 percent were recorded. The experimental header saved between 0.044 and 0.131 m³/ha (0.5 and 1.5 bu/ac) more crop yield than a conventional floating cutterbar. Ground speed had relatively little affect on header losses over the range of 4.02 to 7.24 km/hr (2.5 to 4.5 mi/hr). The new header could travel 2.41 km/hr (1.5 mi/hr) faster than a conventional header with no greater loss. Capability of harvesting narrow rows and long blade wear were also cited as advantages.

Schertz and Nordquist (1975) investigated a draper-extention header which was modified such that the sickle and draper conveyor could float independently of the header frame. They theorized that the

floating design would allow more efficient gathering and that the draper would gently convey the crop to a cross auger. Placement of the cross auger more to the rear of the header also was expected to save many beans from expulsion. The draper incline was 42 degrees. Tests extended over a two-day period. Gathering losses were reduced for three varieties by 2 to 36 percent. The average gathering loss reduction was 12, 29, and 12 percent for Chippewa 64, Steel, and Corsoy varieties, respectively. However, the significance of the reduction was not analyzed statistically. Bichel et al. (1976) reported the development of a "New Concept Header" which utilized a floating sickle. The new header had a larger diameter auger with retracting fingers which helped feed the crop more smoothly. The sickle operated at a 20 percent faster speed of 565 cycles/min. A new structural design added strength to the header. Angular adjustment of the header floor kept the floor parallel to the ground. The floating system rode on skids in contact with the ground. A cantilever spring extended the width of the header to reduce contact force of the skid plates with the ground. A 10.2-cm (4-in) float range was allowed, and the cutterbar was extended ahead of the auger to prevent some grain loss.

Tests of the new header showed a 30 percent reduction in losses. All categories of losses, except stubble loss, were reduced. Shatter loss was reduced by 50 percent. Experiments comparing the new header with a cutterbar extension and with a floating cutterbar showed the "New Concept Header" had a 5.5 percent gathering loss while the other two headers had a 7.5 percent loss.

Green (1907) and Phillips (1954) patented combine header designs which used air to convey plants or loose beans away from the sickle. Recently, much work has been done at the University of Illinois toward using a blast of air to catch shattered beans. Nave et al. (1972) reported an attempt at using the air conveying method. Two 2.24-kW (3-hp) fans and a duct system were installed on a commercial header. An air outlet was formed from a pipe of semicircular cross-section welded just behind the cutterbar with the open side facing the combine. A teardrop-shaped section was placed within the semicircular section with the rounded portion parallel to the rounded section of the pipe. Air passed between the header floor and lower side of the teardrop section until it reached the semicircular pipe. The air then flowed between the pipe and teardrop curvatures until it was expelled rearward over the upper surface of the teardrop. Velocities of 760 to 1220 m/min (2500 to 4000 ft/min) were sufficient to convey material over the extended header floor. Up to $49.6 \text{ m}^3/\text{min}$ (1750 cfm) could be discharged through the 1.27-cm (0.5-in) wide duct outlet over the full width of the combine.

Field tests were run in which five 76.2-cm (30-in) rows were cut at an average height of 10.1 cm (4 in). Sickle speed was 407 cpm and ground speed was 4.8 km/hr (3 mph). The air conveyor header did not have fewer total losses in every variety. However, the air system provided lower, but not significantly lower, shatter losses.

Tate and Nave (1973) reported the addition of a floating cutterbar to the air conveyor system. The cutterbar was extended forward 45.7 cm (18 in) in an attempt to catch shattered beans and to reduce the incline from sickle to auger. The air system remained essentially the same.

Two years of field tests allowed comparison of the floating air conveying system with a conventional floating header, a row crop header, and a standard header. The first year of tests indicated that the air system was significantly better at reducing losses than the conventional header. However, the loss was not shown to be less than that of the floating or row crop headers. The second year of tests indicated that the air system provided lower losses than any of the other headers. Total losses of 5 percent were reported for the air system.

Further improvements to the air conveyor system were explained by Tunnell et al. (1973). The air blast was provided by flood-type sprayer nozzles extended 15.2 cm (6 in) in front of the cutterbar. A laboratory test stand was used to study the system. A 1.5 m (5 ft) wide, standard header platform including the sickle reel and auger was used. Plants were fed into the header on a carriage which traveled at 3.2, 4.8, and 6.4 km/hr (2, 3, or 4 mi/hr). Pans were used to catch various losses. Seven nozzles were mounted 22.9 cm (9 in) apart across the front of the sickle. The nozzle had an orifice diameter of 0.4 cm (5/32 in). A 310-kPa (45-psi) pressure created a fairly uniform air velocity distribution of 914 m/min (3000 ft/min). The system discharged $4.08 \text{ m}^3/\text{min}$ (144 cfm) at 310 kPa (45 psi) with a power requirement of 9.6 kW (12.9 hp).

Tests were conducted on soybean plants with a carriage speed of 3.2 km/hr (2 mi/hr) and a reel index of 1.5. A 1.5 m (5 ft) long sample was taken from the space between two 3.05-m (10-ft) long rows. Stubble, stalk, and shatter losses were measured. Similar tests were performed with a simulated floating cutterbar. Both types of cutterbars provided significant reductions of grain loss. The high horsepower required for

this system, discouraged commercial acceptance.

Wait et al. (1974) reported a follow-up study of the same equipment except that a nozzle with a larger orifice was used. Only 6.9 kPa (1 psi) was needed to provide the necessary air velocity. Less power was necessary to supply the air. Nozzles were moved to a position 11.4 cm (4.5 in) ahead of the cutterbar. Laboratory test conditions were similar to those described by Tunnell et al. except that the soybean moisture content was tested at 13, 11, and 9 percent levels. Nozzles with 1.9-, 2.5-, and 3.0-cm (0.75- 1.0-, and 1-3/16-in) orifices did not reduce losses at a moisture content of 13 percent. The 3.0-cm (1-3/16-in) orifice significantly reduced losses at 11 and 9 percent moisture levels.

Nave and Yoerger (1975) performed field tests on a header equipped with nozzles 38.1 cm (15 in) on center and positioned 15.2 cm (6 in) ahead of the cutterbar. The nozzles were welded to square tubing guards which were attached below existing guards. Orifice diameter was 2.6 cm (1-1/32 in). The header was 4.57 m (15 ft) wide and required 12 air nozzles. Air flow was estimated at $2.83 \text{ m}^3/\text{min}$ (100 cfm) at 6.90 kPa (1.0 psi). Torque measurements on the fan shaft indicated power levels near 11 kW (15 hp) required to supply the air. This arrangement provided an air velocity of 12.7 m/sec (2500 fpm) over the cutterbar.

The air header was compared to a floating cutterbar header in the field. The floating cutterbar cut nearly 1.3 cm (0.5 in) lower than the air header. Ground speed was 4.02 km/hr (2.5 mph). Moisture contents of 14 and 11.5 percent were studied. The air header provided no advantage in harvesting soybeans of 14 percent moisture. However, a

significant reduction of losses occurred at the 11.5 percent moisture level. Total losses were less than 3 percent with the air header.

Rotary blades of various types have been proposed as cutting devices on combines with the intent of cutting plants more smoothly, therefore reducing shatter. Beekman (1938a, 1938b) patented two rotary systems on horizontal shafts. One used conic shell sections like hooks and the other used spiral fingers which also acted like hooks. These blades were not tested for combine use. Durfee et al. (1975) investigated elliptical-shaped disk blades mounted at an angle to a horizontal shaft and which cut against curved ledgers. The blades had removable cutting edges. His purpose was to remove the cyclic loading, vibration, and wear associated with the conventional sickle. This blade was reported to be quite successful at cutting corn stalks.

Bledsoe (1969, 1971) constructed and tested a helical blade on a horizontal shaft for cutting grain crops. His purpose was to reduce disturbance to the crop and to traject plant stems away from the cutting edge onto the header platform. The blade was contained in a 8.9-cm (3.5-in) diameter imaginary cylinder concentric with the shaft axis. Blade edges originated at the tip of a V-shape and extended in a spiral to the left and right. Two such curved V-shaped blades were diametrically opposed on the shaft. Ledger blades provided fixed shear surfaces for the moving blades and were wrapped cylindrically around the front of the rotor. The blade was tested using soybean plants and was found to cut and traject the plant stems effectively over the ground speed range studied. No investigation of shatter loss was done.

Coates (1973, 1975) did a follow-up study of Bledsoe's design in alfalfa and concluded that the helical blade was not suitable for field use in forage crops. The blade would not cut alfalfa stems satisfactorily at high rotor speeds or at high ground speeds. Wrapping of the plants about the shaft was a problem. A stubble height greater than expected was observed.

Hummel and Nave (1977) used a horizontal-plane rotary blade to cut soybean plants by impact. They evaluated the effects of cutter design, plant stem acceleration, and soybean moisture content on soybean shatter. The laboratory test stand and procedures developed by Tunnell et al. (1973) were used in conducting the tests. The blade, resembling a circular saw blade, had notches around its perimeter and rotated about a vertical axis. The diameter was 30.5 cm (12 in) and the thickness was 2 mm (0.08 in). Notch intervals around the circumference of 38, 76, and 152 mm (1.5, 3.0, and 6 in) were tested. Peripheral speeds of 36, 46, 56, and 65 m/sec (7000, 9000, 11,000, and 13,000 ft/min) were used. The blade was mounted on a floating cutterbar system. Ground speed was set at 4.8 km/hr (3 mph) and the reel index was 1.5. Soybean moisture contents were 11 and 13 percent. High speed photography at 500 frames/sec provided plant stem acceleration data. The moisture levels tested did not affect the plant acceleration or header loss values for the new blade. Shatter losses decreased significantly as blade velocity increased. Total header losses from the new blade were not different from that of the floating header. Plant acceleration during impact cutting at 65 m/sec (13,000 ft/min) blade peripheral velocity was significantly lower than for the floating cutterbar.

Schertz (1970) used a rotary blade and soft cylindrical rolls to grasp and convey soybean plants away from the cutting mechanism. His objectives were reduced vibrations, cuts close to the ground, supported plants for reduced shatter, and gentle conveying of plants to the cross auger. The rotary blades were 34.3-cm (13.5-in) diameter disks mounted on vertical shafts. A single blade mounted on one side of the row ran in a horizontal plane centered vertically between two blades mounted on the other side of the row. Center-to-center distance was 30.5 cm (12 in). This arrangement provided a shear type cut when the peripheral speed of the blades was slightly greater than ground speed. Padded cylindrical rollers having a 33.0-cm (13-in) diameter were placed concentrically to the blade shafts. The rollers touched and were compressed near the cutting zone. As the blades cut plants near the ground, the rollers grasped the plants and fed them to the cross auger. The rollers were meant to prevent excessive shatter of beans. No reel was necessary. Field and laboratory tests indicated reduced shatter from the rotary system.

Bichel et al. (1974) described a commercial version of this idea which used gathering belts and a rotary knife to harvest row soybeans. The rotary knife cut by impact near ground level while the belts held and conveyed plants back to the auger. This row-crop header provided 47 percent loss reduction when compared to a flexible cutterbar system. Average of total losses was near 4 percent. Another commercial version utilized opposing rows of brushes instead of belts to hold soybean plants (Implement and Tractor, 1977).

Williams and Richey (1973) described a row crop puller header which grasps and pulls plants. Two all-terrain vehicle tires, running in contact, closed around plants of each row entering the header. The axes of the tires were parallel and tilted 25 degrees from the vertical, thereby creating a lifting force on the plants. Tires were 30.5 cm (12 in) diameter, 27.9 cm (11 in) wide treadless type. A wavy belt carried the pulled plants back to the modified corn header. Both stationary and rotating disk knives were tested with the plant pulling header. The knives were positioned to cut plant stems below the ground surface to reduce the stubble loss occurring with the plant pulling machine. The stationary knives were floating vegetable knives mounted on each side of a row. The rotating knife operated at 900 rpm and was a 5.1 cm (2 in) diameter disk with 1.27 cm (0.5 in) deep notches.

The machine performed better during the initial field tests if the cutting mechanism was removed and the tires were allowed to pull the plants. Total losses were reduced by 71.7 percent when compared to a conventional grain header. However, large weeds caught in the tires, lodged plants were not picked up, dirt entered the combine on the roots of plants, and proper guidance of the row mechanisms were problems.

Boddiford and Richey (1974) continued the investigation of the puller-header concept by modifying a grain platform to accept the row puller units described by Williams. Being shorter, the grain platform was more easily guided in the 76.2-cm (30-in) rows. Other problems faced by Williams were still present. After preliminary tests, a rotary blade was added to cut weeds to prevent jamming. It also cut roots and associated soil from the plants. Field tests of the modified

puller-header indicated its total losses were 46 percent less than the conventional cutterbar.

The reel is another mechanism which causes shatter. Quick et al. (1974) investigated a commercial vertical drum reel system for reducing shatter and lodged losses in row crops. Lamp et al. (1962) blamed the reel impacting and shattering of soybeans during harvest. A reel with tines caused less shatter than one with bats. They developed a reel with bats mounted on chains such that the bats were capable of moving into the grain with zero relative horizontal velocity. Some mechanical problems with the reel prevented its success. Gustafson et al. (1969) used a similar reel for harvesting corn with good results in reducing losses.

E. Need for Further Development

Improvements to the combine header system have reduced losses in harvesting soybeans planted in rows. However, a general purpose header which works as well in drilled or "broadcast" crops as in row crops is needed. Bichel et al. (1974) stated that row crop harvesting machines tended to be row sensitive; that is, guidance of the machine along the row was a problem, and changing the machine for different row spacings was difficult.

Poyner (1966) indicated advantages of a rowless agriculture. He claimed that with existing weed control pesticides, the need to keep the row system was outdated. Closer planting reportedly offers better yields. Cooper (1971) stated that narrow row spacing in soybeans resulted in higher yield when lodging was not a problem. Nave and Cooper

(1974) also indicated higher yields in 17.8-cm (7-in) rows under moderate seeding rates of 371,000 seeds/ha (150,000 seeds per acre). In addition, Quick et al. (1974) showed that narrow row spacing could considerably reduce header losses in soybeans. The reduced losses came partly because pods formed higher on the stalk of narrow-row soybeans; thus pods were positioned away from the cutting zone. Quick reported one test with 25.4-cm (10-in) rows in which yield was 19.9 percent greater and header loss was 22.7 percent lower than with 76.2-cm (30-in) rows. A typical seed distribution on plants was also given which emphasizes the need for cutting low, 7.6 cm (3 in) or below.

This investigation considered the actual cutting process. Many researchers (Kepner, 1952; Harris, 1956; McClelland, 1958; Chancellor, 1958; Feller, 1959) have studied the basic elements of cutting plant materials. Bledsoe (1969) did an extensive collection and analysis of literature containing information on cutting.

Cutting by conventional reciprocating blades is accomplished by a shearing action between two elements. Stationary ledger plates in the guards act as shear plates to hold the plants. The reciprocating knives push plants against the ledger plates and apply sufficient force to sever the stems.

Some new crop header systems use single element or impact cutting to sever stems. Impact cutting requires high blade speeds. The mass of the plant provides inertia which serves to hold the plant still while it is being penetrated by the single blade (Chancellor, 1958). Energy imparted to the plant is affected by blade speed and stem diameter. This imparted energy results in a rotation and translation of severed stems.

The motion of a blade perpendicular to the direction of entry of the plant into the harvesting machine results in a slicing or sawing cut. The normal force on the plant determines the distance that the stalk moves along the blade before the plant is severed (Feller, 1959). The wedge action of a knife causes tension failure of the plant fibers to precede the leading knife edge. Chancellor (1958) claimed that during slicing the blade edge causes fibers to bend in the direction of blade motion due to friction or edge irregularities. The fibers, then, might fail from either bending or tension stresses or from a combination of the two.

Sawing is slightly different from slicing. In sawing, the blade edge positively engages fibers of the stem. These fibers may fail from either shear, tension, or bending stresses, or from a combination of these stresses. Harris (1956) described the failure of wood during sawing as a shear failure. Saw teeth are usually offset such that a kerf (notch wider than the blade itself) is produced. The formation of this kerf requires the cutting of the plant stems in two parallel planes.

Chancellor (1958) reported that slicing and sawing type cuts required less energy than shearing. The force normal to the blade edge exerted by the material being cut affected cutting energy. For smooth blades, increased normal force decreased the required cutting energy. He also showed that the ultimate tensile strength of plant fibers had some effect on the required energy.

One might assume from the literature, then, that a continuous loop cutting device might perform at lower normal levels if some form of positive plant engagement by the edge is allowed. Knife or serrated-edge

cutters require either too much energy or demand high normal forces. High normal forces would tend to excessively disturb the plants, causing shatter, before the cut was completed. A blade which would cut quickly through the stems at low energy levels would be ideal.

Continuous loop blade devices have been proposed for cutting both forages and grain crops. Graverson (1971) proposed mounting special blades on a V-belt. The belt ran in a continuous loop in a horizontal plane and provided impact cutting when blade speed was fast enough. Locati (1970, 1972) proposed similar systems, one of which was a self sharpening version. Hofer (1968) patented a continuous loop system in which blades similar to conventional sickle sections were mounted on a belt and run such that returning blades would slice against the backs of advancing blades. Thus a two element shear cut was provided if the blades were kept close together while they traveled in opposite directions.

Teel (1977) reported the development of a belt cutting system. A V-belt having "C" size width and a "B" size depth was used to carry cutter blades formed from sheet metal. Blades were attached by a simple pin connector which passed through the flat sides of the belt. Pulleys were in a horizontal plane. A 15.2-cm (6-in) cutter spacing along the belt and a peripheral speed of 2440 m/min (8000 ft/min) allowed a ground speed of 12.1 km/hr (7.5 mph). Cutting tests did not involve soybean plants.

Investigators have used methods other than belts to provide continuous loop cutting mechanisms. Quick (1972) patented a system that had a chain carrying conventional blade sections in a horizontal plane.

Two chain loops were used, extending from the center of the combine header toward opposite ends of the header. On each chain loop, the forward cutting edge of each blade section traveled toward the end of the header such that cut stalks would be better oriented for feeding into the cross-auger. Three plant dividers, one at each end and one at the center of the header, were necessary for this arrangement.

A steel cable in a horizontal plane was proposed as a cutting device by Henzman (1970). A V-belt carrying a steel cable acted as the carrier for sawing or impact cutting elements. Henzman suggested that wires or spikes be inserted at various angles through the cable to act as cutting elements.

Kepner (1959, 1967) utilized a band saw to harvest white and green asparagus. The blade was 5.18 m (17 ft) long and 0.559 mm (0.022 in) thick. The blades ran underground (through plant beds) with a tension of about 1334 N (300 lb). Width of the blades was 1.90 cm (0.75 in). Smooth edge, notched edge, V-toothed, and wood cutting toothed blades were tried at speeds up to 5180 m/min (17,000 ft/min). Band wheels were 45.7 cm (18 in) in diameter. The most successful combinations were the notched blade at 1520 m/min (5000 ft/min) and the V-toothed blade at 460 m/min (1500 ft/min). Wear of the blade was a major problem. A slow blade speed was desirable to reduce wear. A V-toothed blade at 460 m/min (1500 ft/min) lasted approximately 5 hours in sandy loam or 35-40 hours in peat soil. Hardened blades reduced wear but produced fatigue cracks after less than 2 hours of operation at 460 m/min (1500 ft/min). A tungsten carbide coating proved useful in slowing wear.

F. Inferences

New concepts for saving grain are available on current combine headers. However, a combine header which provides reduced losses and the capability of operating in broadcast, drilled, or narrow row crops is not available. Such a header is needed. It should cut close to the ground and follow ground contours to avoid stubble loss. It should reduce plant acceleration and vibration to decrease shatter loss. The reel should be designed to reduce plant agitation. Losses of less than 3 percent in soybeans would be desirable.

CHAPTER III

DESIGN AND CONSTRUCTION

A. Introduction

A combine which will harvest narrow-row or broadcast crops must have a cutting device across its total width. To cut low on the stalk, the blade must be close to the ground. A band saw blade was chosen to provide a cutting action for reduced vibration and acceleration in soybean plants. This blade provided a cutting surface which was close to the ground and was capable of harvesting plantings of any row width. The band moved horizontally across the cutting zone of the header near the ground, traveled vertically up one side until enough clearance was gained for soybean plants to pass through, then completed the rectangle necessary for continuous loop operation.

A Chain Machine Company model SP-50 plot combine was available for use in this project. An entirely new header was constructed for use with the plot combine to allow for more design flexibility and to allow comparisons with the conventional header. Figures 1 and 2 illustrate the conventional and new headers.

B. Header Framework

The framework of the conventional, general purpose header served as a model for the basic framework in the new header. A 2.54 cm (1.0

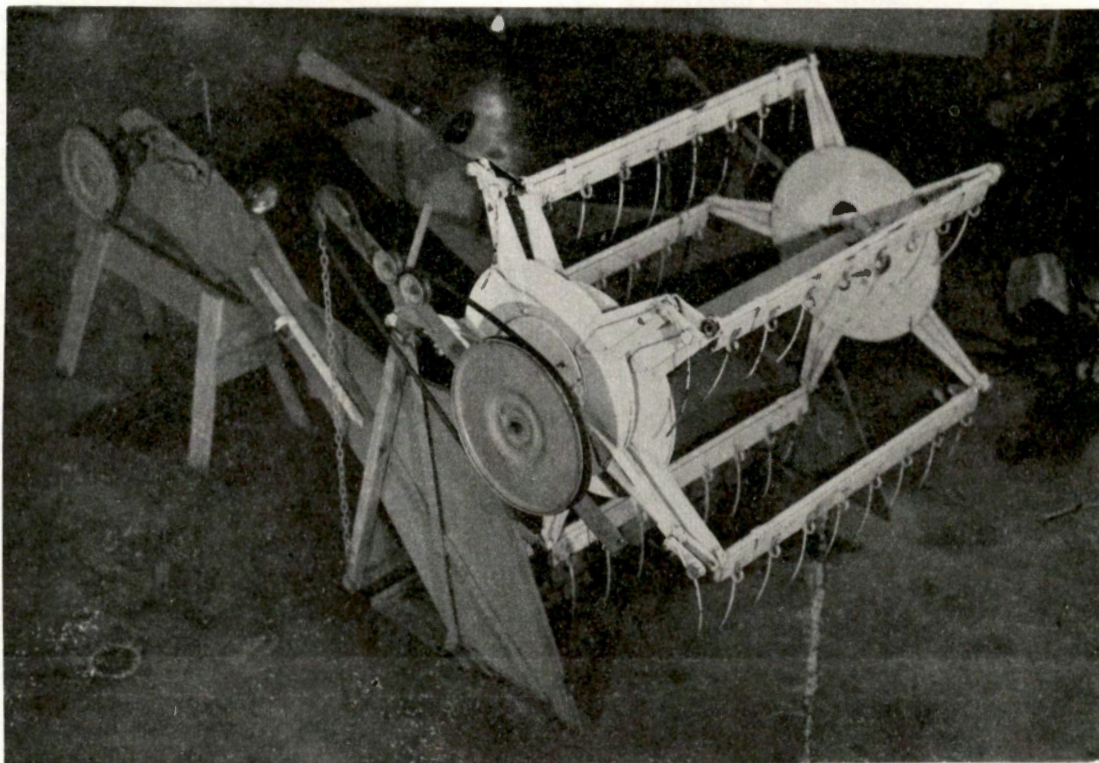


FIGURE 1. Conventional SP-50 header.

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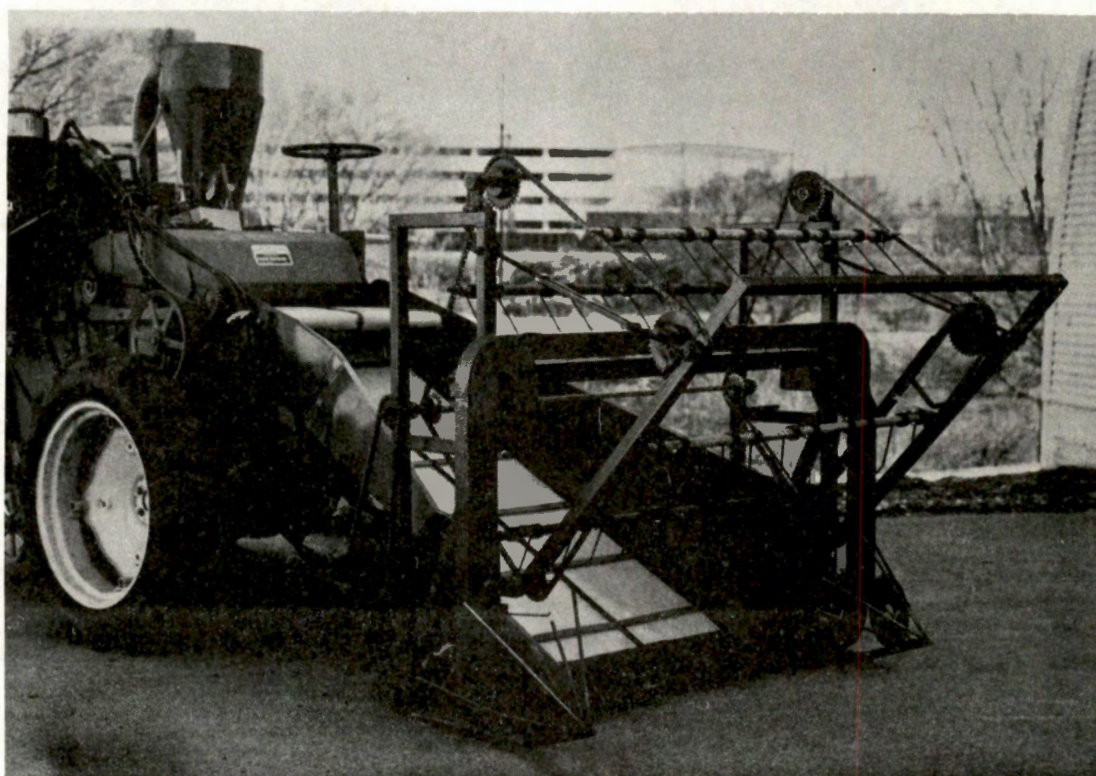


FIGURE 2. New band-blade header adapted to the SP-50 combine.

in) diameter solid steel shaft served as a mounting support and drive shaft. Two cast steel pillow blocks attached to the combine front framework supported the shaft. The shaft also passed through two cast steel flange bearings attached to the header framework. This design allowed header rotation around the horizontal shaft with rigid support in other directions.

The right end (facing forward, in the direction the machine would travel in the field) of the shaft extended past the header framework and held a V-belt pulley and two sprockets. The pulley was driven from the combine main drive shaft. One sprocket drove the sieve shaker crank on the combine. The other sprocket drove a flat conveyor belt which helped feed plants to the cylinder. A 5.1 cm (2 in) diameter pipe, welded concentrically to the support shaft, drove the flat belt which conveyed plants from the blade to the threshing cylinder.

In the conventional header, the left end of the support shaft, which extended beyond the header framework, held an eccentric stub shaft. This stub had an offset of 3.8 cm (1.5 in) and drove the reciprocating cutterbar. A long pitman transferred the eccentric motion to a rocker linkage which was connected to the sickle. This construction was not necessary in the new header, of course.

The main header framework consisted of two 3.8 cm (1.5 in) steel angle pieces which were attached to the cast steel flange bearings at the support shaft. These pieces ran parallel, forward, and downward at an angle toward the cutterbar supports. These pieces were stiffened by welding 3.2 cm (1.25 in) square steel tubes to the inside of the angle.

Attached to the framework angles were two pairs of support brackets. One pair served as mounts for hydraulic cylinders which raised and lowered the header. The other pair of brackets were points of attachment for a pair of support arms. These arms were connected to a pair of springs through a rocker arm mechanism. The springs could be adjusted such that they supported all or a portion of the header weight. This action allowed the entire header to "float" on the skid plate during its operation.

Lower ends of the frame angles terminated along 0.64 cm (0.25 in) thick plates placed vertically in the same plane as the frame angles. The top edge continued the same angle as the frame pieces while the bottom edge was cut to run nearly parallel to the ground when the header was in a cutting position. A 0.32 cm (1/8 in) thick skid plate the width of the header was welded to the bottom of the frame plates. The skid plate was also welded to a 6.0 cm (2-3/8 in) diameter structural steel pipe to the rear of the frame plates. This pipe was welded to the support rod brackets and provided structural rigidity. The pipe also provided a smooth surface to ride over soil if the combine were backed up while the header touched the ground.

The front tips of the frame plates were notched to accept the 3.8-cm (1.5-in) angle which would later be part of the band framework. The skid plate and a 0.95 x 3.8 cm (3/8 x 1-1/2 in) spacer plate were welded together to provide rigidity in the front. The spacer plate had threaded holes to which the band framework was to be bolted. Sides of the skid plate area were reinforced with 5.1 x 2.5 cm (2 x 1 in) steel channels positioned on edge. The channels were welded to the support

pipe and the skid plate but had holes for bolting to the band framework on the forward end.

The sides of the header were formed of 16 gage (1.52 mm (0.0598 in)) sheet steel. The shape of the sides was copied from the existing header except in the vicinity of the band framework. Near the rear of the header 11 gage (3.04 mm (0.1196 in)) sheet steel was used to form the sides. This feature also was copied from the original header and was needed for support of the feeder belt conveyor.

C. Conveyor Belts

The feeder belt was positioned above the main conveyor belt such that it compacted the plant mass as plants were fed to the cylinder by the main conveyor belt. Figure 3 illustrates the feeder belt arrangement on the header. Both the main conveyor belt and the feeder belt were 71.1 cm (28 in) wide, 5-ply, "food handling belt." The belts originally ran on 5.1 cm (2 in) diameter pipes concentrically welded to shafts; the main drive shaft was mentioned earlier. The main conveyor belt idler shaft extended through slots in the frame plates. The feeder belt shafts were mounted in the heavy sheet metal in the throat of the header. Tension to the belts was provided by threaded rods which supported the idler shaft bearings. Supports for the threaded rods were bolted to the framework.

The conveyor belts did not track correctly on the pipe rollers. They tended to pull to one side with considerable determination no matter what tension adjustments were made. A fiberglass matt and polyester resin layer was applied to the rollers. This layer was turned

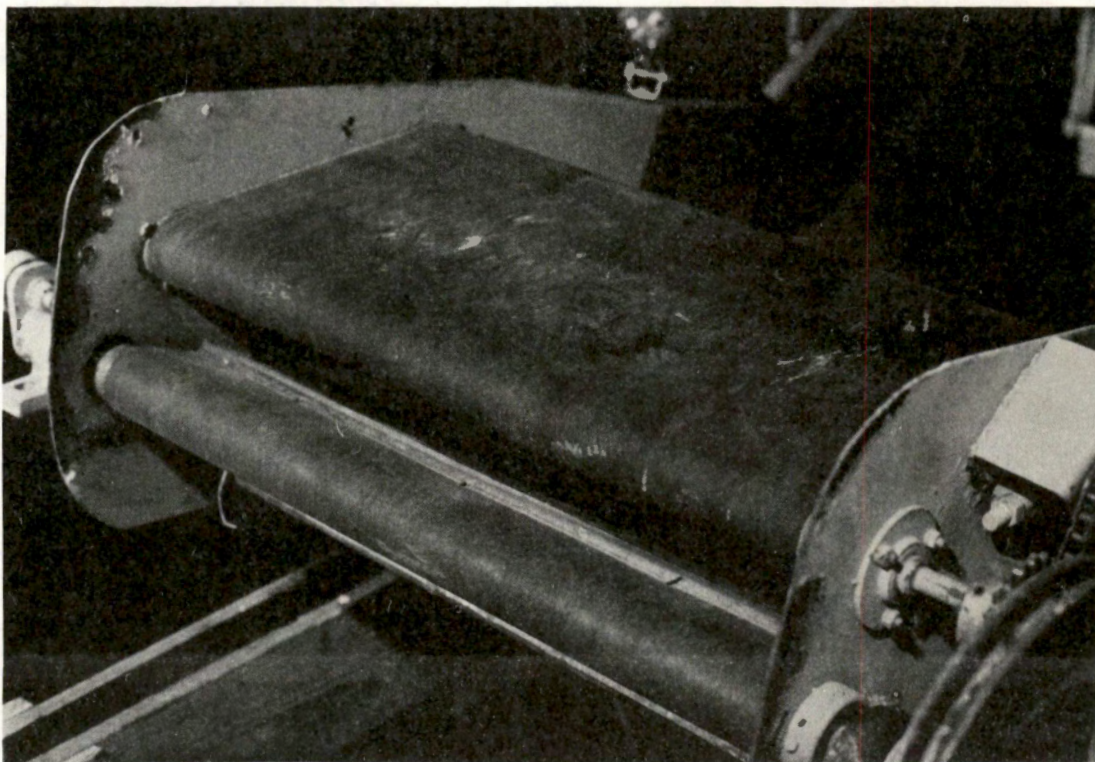


FIGURE 3. Main conveyor and feeder belt arrangement on headers.

on a lathe to produce a 0.32-cm (1/8-in) crown in the center. Although the crown helped tracking, the belts still pulled to one side. The belts were split in the center and attached to a number 40 roller chain having attachment links at 5.1-cm (2-in) intervals. Blind rivets (pop rivets) were used to attach the chain. Wood slats 2.5 cm (1 in) wide and 0.64 cm (0.25 in) thick were attached to the conveyor belt at 30.5-cm (12-in) intervals with blind rivets. The feeder belt had no slats. The belt rollers were removed and replaced by shafts. Sprockets were centered on the shafts and carried the chains and belts. Wood cylinders 4.4 cm (1-3/4 in) in diameter were placed to each side of a sprocket to help support the belts.

D. Bandwheels

The bandwheel design was a result of a compromise between wheel size and blade stress requirements. The lower wheels were near the ground in a vertical plane facing the oncoming crop. The plants had to be routed around the wheels, either into the header or outward to one side. This consideration dictated as small a wheel as possible to reduce plant agitation and to avoid longer stubble in the area that passed under the wheels. The blade bending stresses were defined by Spotts (1971) as

$$S = Ev/r$$

where

S = bending stress, psi,

E = modulus of elasticity, psi,

v = half the blade thickness, in, and

r = radius of wheel, in.

This equation indicated that larger diameter wheels produce lower cyclic stresses in the blade. Lower stresses would increase the useful life of the blade. A 20.3 cm (8 in) nominal diameter was selected to give an acceptable stress level while allowing plants to be divided.

Four bandwheels were constructed from cast steel gears. The gear teeth were machined on a lathe until a 21.0 cm (8.25 in) diameter, 2.9 cm (1-1/8 in) wide smooth face remained. A portion of the face was further machined leaving a 0.64 cm (0.25 in) wide, 0.32 cm (1/8 in) thick flange at the back of the face. The face of the wheel carried the band and was 20.32 cm (8.00 in) in diameter and 2.2 cm (7/8 in) wide. The hubs on three of the wheels were bored to accept ball bearing cartridges with a press fit. The front bearings had locking collars for adjustment along the shafts. The fourth wheel was bored to a 2.54-cm (1-in) diameter and keyed to a drive shaft. The band wheel is shown in Figure 4.

E. Blade Adjustments

Proper blade tracking was obtained by manipulation of "pitch-yaw" adjustments. The upper right and lower left band wheels were attached to these devices. Two bolts provided adjustment of the wheels around two perpendicular radial axes. The rear bolt was mounted vertically and was threaded to a metal block. The block would move vertically when the bolt was turned. The wheel axle was 2.54 cm (1 in) square steel turned to a 2.2-cm (7/8-in) diameter at the wheel end. A horizontal pin joint connected the metal block and axle and allowed the axle to pivot relative to the block. The forward bolt passed through a threaded hole in the

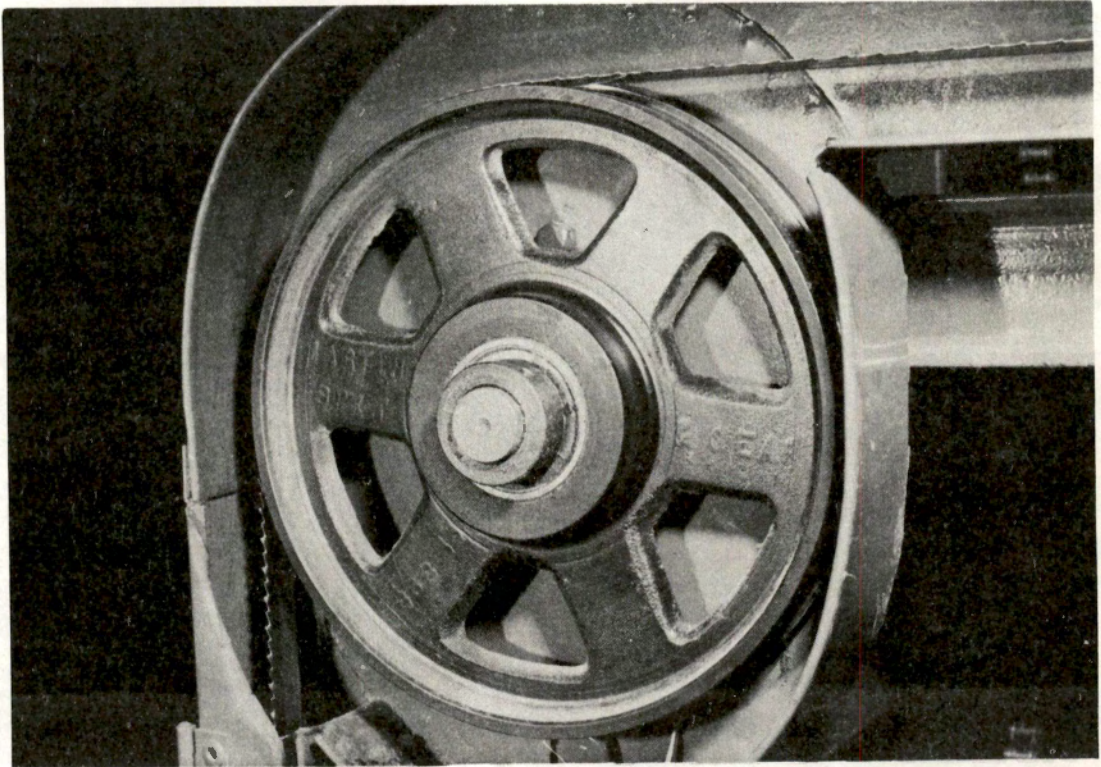


FIGURE 4. A band wheel.

axle near its middle. The forward bolt was used to pull the axle away from the frame, causing it to rotate about the rear bolt. This caused the wheel to rotate about a vertical radial axis and to translate horizontally a slight amount. The rear bolt pulled the metal block vertically causing the axle to rotate about a horizontal radial axis and translate vertically. A 0.95 cm (3/8 in) thick plate supported the devices. A completed "pitch-yaw" mechanism is shown in Figure 5.

Blade tension was provided by a sliding block (Figure 6) which carried the upper right wheel. The block was 2.5- x 5.1-cm (1- x 2-in) steel with a 2.2-cm (7/8-in) diameter axle turned on the end. The block could slide vertically on two 1.27 cm (0.50 in) diameter rods. A 1.6-cm (5/8-in) bolt was threaded into the block and provided a rigid pulley adjustment. Mote (1969) claimed that a floating or spring loaded pulley system was somewhat more stable at high speeds than a rigid system. However, a rigid system operated with a lower band stress at high speeds. The dynamic tension in a bandsaw blade was due to the centrifugal force on the blade as it passed a bandwheel. The dynamic tension plus the static tension provided the operating tension used to calculate the tensile stresses in the blade. Mote showed that for a rigid system the blade tension remained constant. As the blade traveled faster the dynamic tension increased and the blade expanded, thus reducing the static component by an equal amount. A spring loaded or floating wheel system maintained all or part of the static tension component, thus providing a higher tension in the blade.

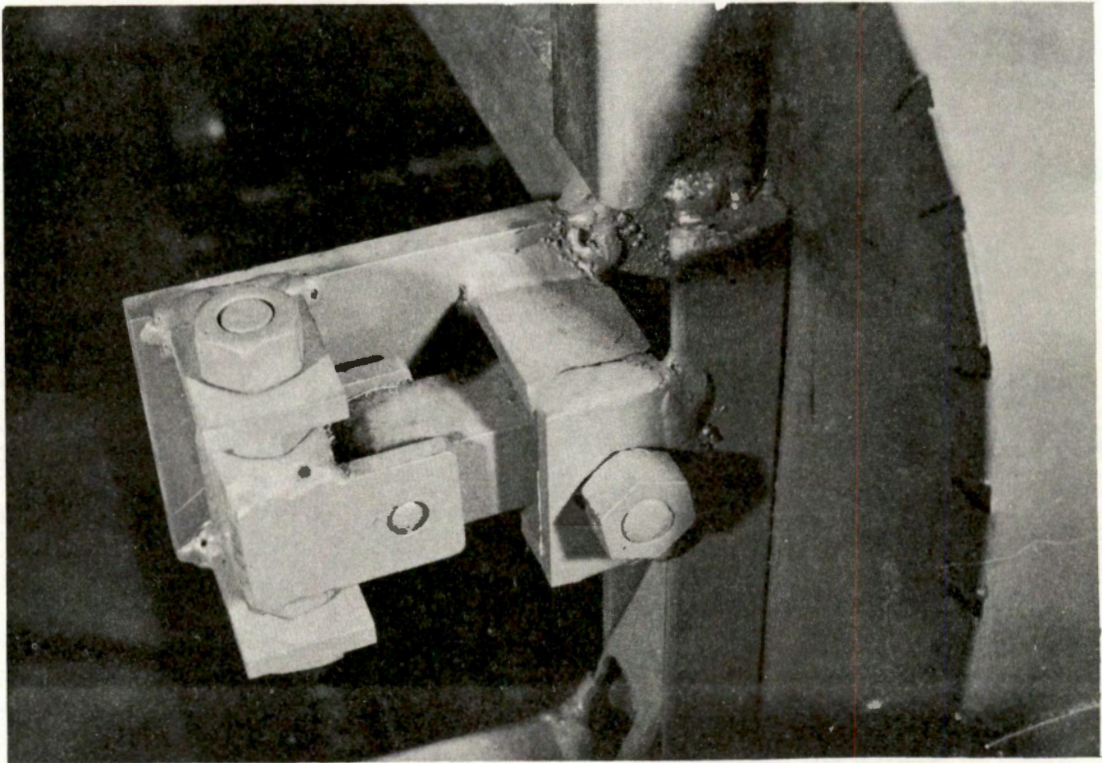


FIGURE 5. "Pitch-yaw" adjustments of bandwheels.

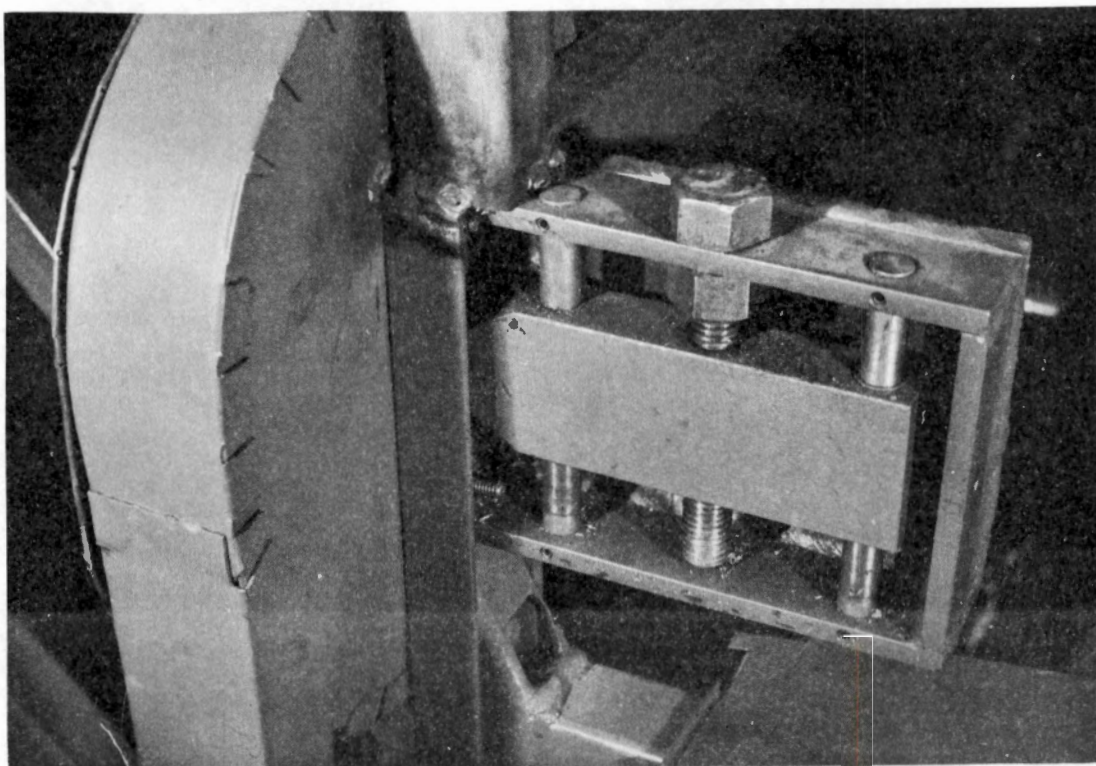


FIGURE 6. Blade tension adjustment.

F. Blade Framework

A frame (Figure 7) to hold the four bandwheels in position was constructed such that it could be easily removed from the new header for modification. A 3.8-cm (1.5-in) angle was attached to the skid plate and reinforcing plate by 0.95 cm (3/8 in) round head machine screws at 15.2-cm (6-in) intervals along the width of the header. Two 5.1 x 2.5 cm (2 x 1 in) steel channels were welded vertically to the angle with the broad flat side forward. A 5.1- x 2.5-cm (2- x 1-in) channel was welded horizontally at the top of these uprights. This rectangular frame was braced to the support pipe by 3.8 cm (1.5 in) box steel members on each side of the header. The framework provided an open width of 137 cm (54 in) and a clearance height of 84 cm (33 in). The backing plates of the pitch-yaw adjustments and the tension adjustments were welded to the frame. All four axles passed through holes in the upright channels.

The drive wheel and shaft were placed in the lower right corner to provide drive tension to the exposed cutting surface of the band. A 0.95 cm (3/8 in) thick plate welded to the upright channel supported two pressed steel pillow blocks. The drive shaft was free to turn in these bearings. The end of the shaft opposite the wheel was free to accept driving elements.

G. Shields and Guides

Shields were constructed around all of the wheels and parts of the blade not exposed for cutting. A channel was formed of 18 gage (1.21 mm

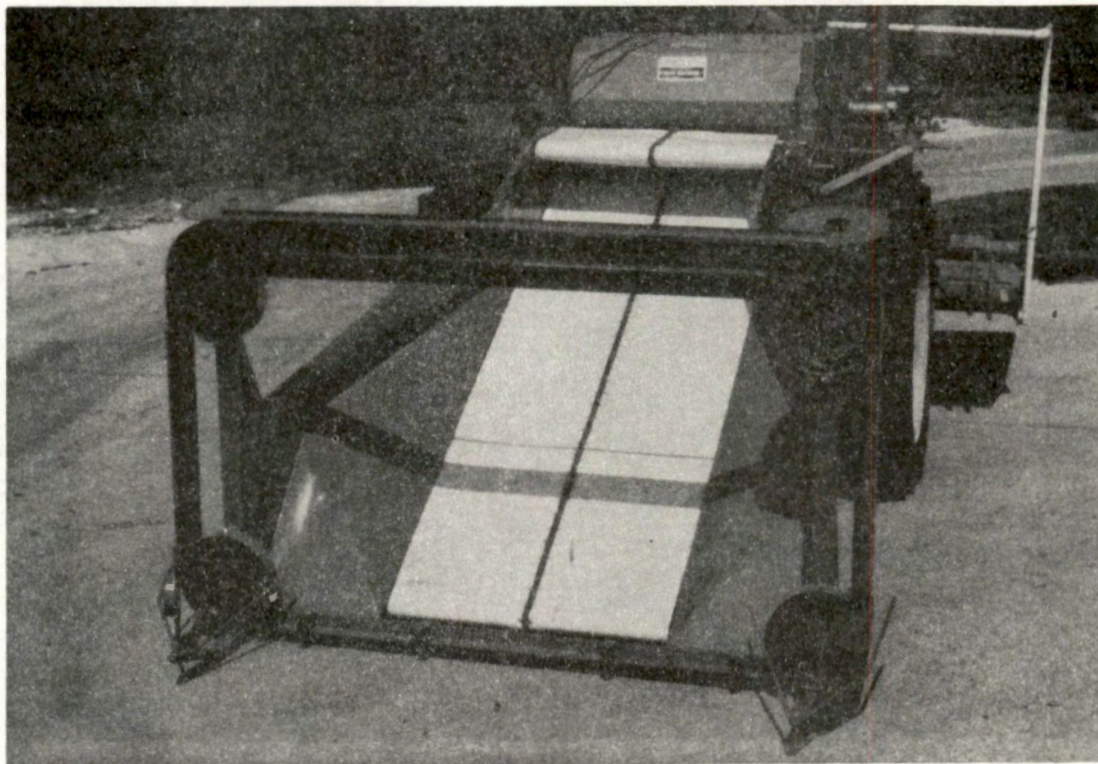


FIGURE 7. Blade framework and bandwheels.

(0.047 in)) sheet steel around the sides and back of the wheels and blade. A hinged cover protected the front edge of the blade and allowed easy access for blade removal. The entire wheel-blade shield was bolted to the frame and was removable.

Plant dividers were provided to separate the plants around the bandwheels and to lift some lodged plants. A 3.2 cm (1-1/4 in) steel angle was welded to both outside edges of the bottom of the skid plate beneath the lower bandwheels such that the right angle was pointing downward. These two pieces were bent upward slightly where they extended in front of the header to allow them to ride over larger obstructions and prevent the blade from digging into the soil. These angles were meant to slice into soft soil and therefore not add appreciably to the cutting height. Two 0.95 cm (3/8 in) diameter steel rods extended from the tip of each of these angles. These rods extended to the rear and upward toward the edges of the wheel. They lifted and separated plants to allow them to pass around the lower bandwheels.

The band was exposed as a cutting surface across the header width and was subject to twisting and vibrations when cutting plants. Four guides were constructed and placed 23.9 cm (9 in) and 53.3 cm (21 in) from the center of the exposed cutting area. Each guide consisted of a two-piece U-shaped block and three cam follower bearings (Figure 8) bolted to the lower blade frame angle. One of the bearings was bolted to the block by passing a bolt through the two arms and the bearing. This supported the back edge of the blade with a rolling surface and prevented its rearward motion. Two bearings were bolted onto the ends of the arms. The rolling surfaces of these bearings contacted both sides

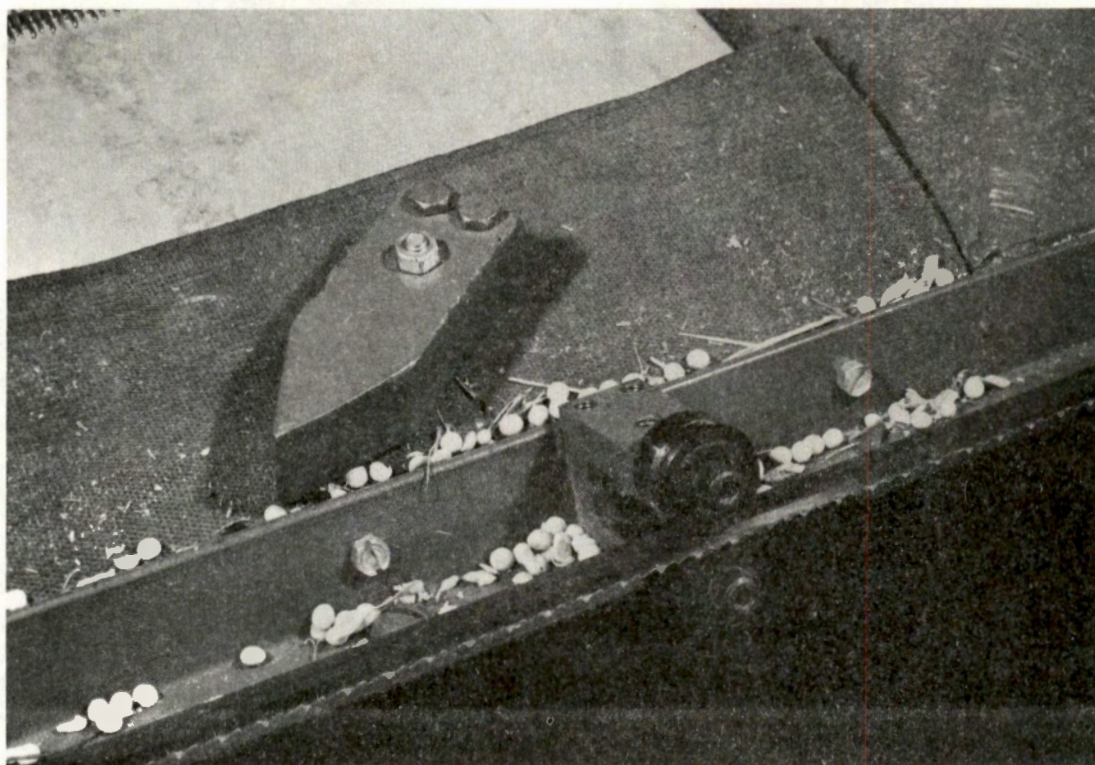


FIGURE 8. A blade guide with shield (angular tipped object) removed.

of the blade and prevented its twisting. Shields covered the top and sides of these devices to prevent the entanglement of plants. The leading edges of the shields were tapered to allow for smooth flow of plants around the guides.

The installation of finger type guards similar to conventional guards was considered for protection of the blade. However, they were omitted due to the cost of construction and the experimental nature of the project.

H. Blade Drive Design

Because of space and speed requirements and cost, an electric drive system was selected to power the blade. A 24V, 75A, DC electric generator was mounted on the combine engine and driven by a V-belt. The voltage output was regulated manually. A 10 ohm, 3.8 A rheostat regulated the field current which governed the output as indicated by a meter in a control box containing the rheostat and control switches. A 24V solenoid switch controlled the supply line to the motor. Supply wires were 6 AWG multistrand type cable.

The electric motor was rated at 1.1 kW (1.5 hp) at 7000 rpm. Current rating was 50A. A high speed motor was selected because of its small size. The drive system was mounted on top of the skid plate in the space between the conveyor and the outside edge of the header. The sheet metal which formed the sides of the header severely limited the space. The top of the skid plate served as a sliding surface for a base plate attached to the motor. Two removable rails clamped over the edges of the base plate and allowed it to slide away from the blade drive shaft.

A poly-V belt from the motor drove a transfer shaft carried by bearings mounted on a plate which was hinged to the motor bracket. The opposite end of this shaft powered the blade drive shaft through a variable pitch pulley and V-belt. The hinged shaft carrier was positioned at an angle of about 45 degrees away from the blade drive shaft. The transfer shaft was positioned nearly vertically above the motor shaft. A screw forced the motor-bracket-transfer shaft assembly to move away from the drive shaft. V-belt tension pulled perpendicular away from the motor. This action provided tension in both belt drives. A compact electric drive with some speed control resulted (Figure 9).

I. Reel Design

The return path of the blade prevented use of the conventional reel from the original header. The chain-bat reel described by Gustafson et al. (1969) seemed particularly well suited for application in this project. The returning blade could pass through the chain loops that carried the reel bats. The chain-bat construction promised further grain savings if properly designed.

The chain-bat design for the band-blade header is shown in Figure 10. A framework of 3.8 cm (1.5 in) square steel tube was welded to the support pipe and blade frame braces. A 1.3 cm (5/8 in) diameter steel drive shaft was mounted to the rear of the blade framework over the conveyor belt. A second set of sprockets was mounted just above and behind the returning path of the blade. A third set was mounted on a framework which extended ahead of the header on a 3.8 cm (1.5 in) square tube frame. The reel frame was free to pivot about two stub shafts which

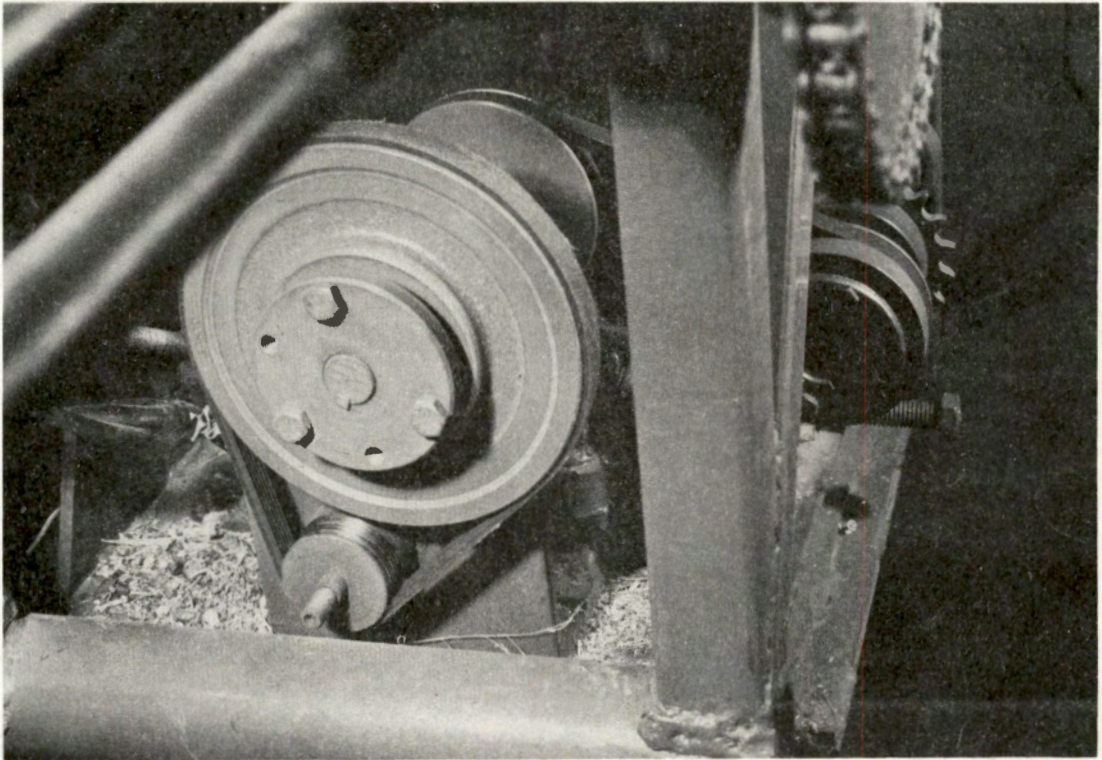


FIGURE 9. Electric blade drive.

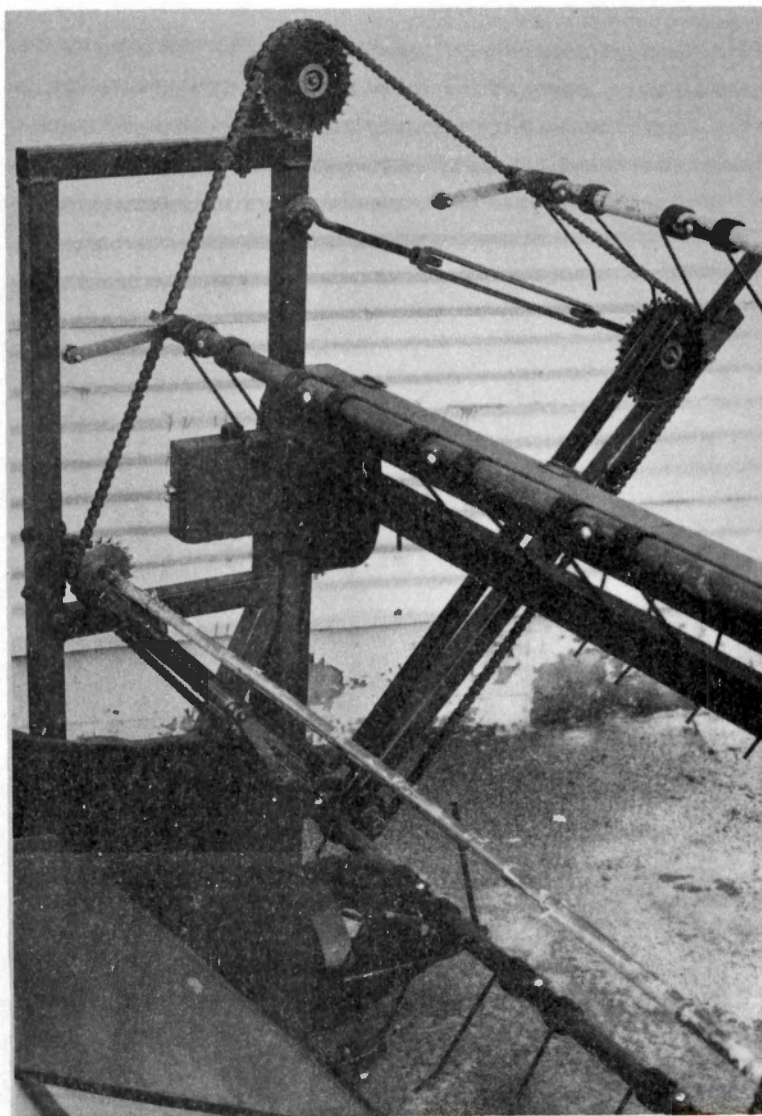


FIGURE 10. The chain-bat reel.

were fastened to the blade frame. These shafts also supported a fourth set of sprockets just above the cutting surface. A pair of springs and steel cable provided tension between the plant separators and the reel frame. This kept the chain tight. The path of the chain from the fourth set of sprockets was nearly parallel to the sheet metal bottoms on each side of the conveyor. The tines carried material up the incline of the metal sides and then released it onto the conveyor.

The path of the chain from the forward sprockets to the lower sprockets was, of course, approximately a straight line. Gustafson et al. (1969) pointed out that a zero horizontal velocity relative to the grain was possible with such a reel. Figure 11 indicates some of the parameters discussed by Gustafson in the design of a chain bat reel. V_B was the chain velocity. V_C was the forward speed of the combine. The bats traveled downward into the grain at an angle θ from vertical relative to the combine frame. After passing the blade the bats traveled rearward and upward at an angle ϕ from horizontal relative to the combine frame. The bats entered the plants with a zero relative horizontal velocity if

$$V_B = - V_C / \sin \theta.$$

Gustafson further found that the reel would convey plants away from the cutterbar efficiently when a constant $A > 1$ was provided such that

$$V_{P/H} = - AV_C = \frac{\cos \phi}{\sin \theta} V_C.$$

Also, the bar spacing, S , was found to be most effective when it was greater than the plant length. The amount of forward travel between

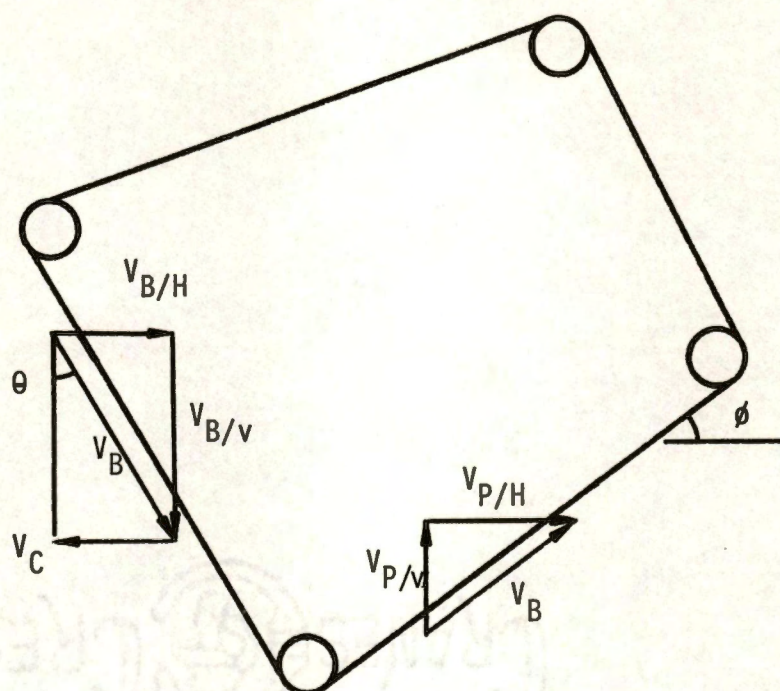


FIGURE 11. Parameters used in the design of a chain-bat reel.

passage of reel bats, D , was found from

$$D = S \sin \theta.$$

The reel constructed for this project had an entry angle, θ , of 56.6 degrees. A general purpose bat spacing of 76.2 cm (30 in) was selected. The combine would travel 63.6 cm (25 in) between sweeps. To obtain a zero relative horizontal velocity to the grain, the chain traveled at 1.57 times the ground speed. The angle ϕ as constructed was 46.1 degrees. The constant A had the value of 0.83 which was less than that recommended by Gustafson. He based his calculations on the horizontal velocity component of the chain velocity as it receded from the cutterbar, but the material would be removed from the cutterbar with the speed of the bats. Since the chain speed was greater than ground speed, the material should have been adequately removed from the cutterbar area.

The original reel bats were wood. Four oak boards measuring 120.6 x 9.8 x 1.9 cm (47-1/2 x 3-7/8 x 3/4 in) were fitted with brackets at each end. The brackets were hung by attachment links on the reel chain. Five metal, spring-wire, double-tine, rake teeth were spaced uniformly across each bat. Tines were necessary since the header design required the reel to convey plants up the steep header floor. The mass of the wood bats was sufficient to cause significant problems during acceleration around the sprockets. This arrangement was never tried in the field. The possibility that plants might be pulled along with the reel bats back around the reel path was considered. Since the tines were nearly perpendicular to the chain and rotated as they passed over a

sprocket, they would have a lifting motion at the position where plants were to be left on the conveyor.

For these reasons the reel bats and chains were modified to allow the bats to pivot relative to the chain. Chain attachment links were riveted to an L-shaped metal block. The block fit on the chain such that a 0.48 cm (3/16 in) diameter 3.8 cm (1-1/2 in) long hardened dowel could be mounted parallel to, and in the same plane as, the chain pins. Small cylindrical bushings were pressed into the wood bats at each end 2.5 cm (1 in) from the top edge. The bats could swing freely on the dowels. Chain tension prevented the bats from falling from the dowels. A cam system to provide parallel motion of the bats was planned. However, before the cam was constructed it was discovered that the wood bats were still too massive and considerable rotation was observed as they passed the sprockets. For this reason, the wood bats were abandoned. New bats were constructed of 27.0 mm (1-1/16 in) outside diameter, 120.6 cm (47.5 in) long water pipe. The four pipe bats were plugged at each end and center drilled to pivot on hardened dowels. The dowels were 6.4 mm (0.25 in) diameter, 4.4 cm (1.75 in) long hardened steel. The tines were removed from the wood bats and bolted to the pipe. Tines were 15.2 cm (6 in) long.

The reel was driven by the hydraulic motor from the original header. A chain sprocket was bolted to the V-belt pulley such that the motor would work with either header. The new reel was driven by chain while the conventional reel was driven by V-belt.

The reel tines were kept nearly vertical during entry between plants and during the conveying of cut plants away from the blade. A

12.7 cm (5 in) long lever was attached to each pipe bat. The lever carried a ball bearing 2.2 cm (7/8 in) in diameter. As the bat approached the plant entry section the bearing was trapped in a 3.2 cm (1-1/4 in) wide, 1.3 cm (0.5 in) deep channel. The bearing followed this channel down to the lower sprockets just above the blade. As the bats passed the blade the channel made a bend to follow the conveying section. The tines made a slight sweeping action as they passed the blade. The channel guided the tines along the conveyor until the bearing was freed near the drive shaft. The weight of the tines and the bearing held the bats in a position that allowed the bearing to be caught by the channel again.

CHAPTER IV

LABORATORY ANALYSIS

A. Introduction

Laboratory tests performed during the fall of 1977 explored the feasibility of the band cutting system. Field experiments were planned, but the initial reel design, which included wood bats, failed to operate satisfactorily and prevented field operation. The wood bats were dynamically unbalanced and the acceleration around the sprockets caused violent rotations of the bats as they entered the grain. Threshing of the soybeans by the bats was inevitable.

Laboratory tests can provide valuable information. Quick (1973) listed several advantages in using laboratory tests to study header losses in soybeans. A loss-catching frame beneath a field-going header, he said, was impractical due to the low cutting height required. He also claimed that proper evaluation of the separate header loss components could not be accomplished properly in the field due to interdependence of the components. Laboratory tests produced higher statistical reliability from a smaller sample size. Other advantages listed by Quick included elimination of the weather factor, better control over experiment variables, and isolation of the causes of losses. High speed photography could also be used in the laboratory.

Quick designed a laboratory test stand (described earlier) for use in combine header evaluation. Tunnel et al. (1973) developed a similar test stand which was used in that and other experiments (Hummel et al., 1977). The header was stationary for both test stands. A carriage held and propelled plants into the header in an upright position. The various losses were collected in trays on either side of the carriage. The carriage speed was regulated to simulate different ground speeds. Adjustments or additions to the header were easily applied and tested.

B. Statistical Design

The purpose of the laboratory tests was to determine if the selected blade reduced the header losses. Shatter loss was of particular interest since it offered the possibility of greatest improvement. The effects of blade speed and ground speed on the various losses were observed.

The laboratory tests were performed in a randomized complete block design. Four blade speeds and four ground speeds were applied in a factorial arrangement of treatment combinations randomized within each of three blocks or replications. A test of the conventional plot header was included in each replication. The response variables measured were percents of shatter and other losses.

C. Equipment for Shatter Tests

A test stand was constructed to facilitate the laboratory tests. The conventional SP-50 header was mounted on the plot combine in the

normal manner. The reciprocating blade was driven by the usual mechanism, but the conveyor belt was loosened to prevent it from feeding plants into the combine. The conventional reel was removed from the header to eliminate it as a cause of shatter losses. The wheels of the combine and bottom of the header were placed on 14 cm (5.5 in) high wood blocks to allow room for a plant carriage. The wheels were blocked to prevent excessive motion of the combine.

The rear of the band-blade header was supported by wires from a metal A-frame. The front of the header was placed on 14 cm (5.5 in) high blocks. The new header was located to the right of and slightly to the rear of the conventional header. Conveyor belt power was not required. The blade drive was powered by the generator on the combine.

The plants were conveyed into the blades by a mechanism consisting of a U-shaped track, a plant holding carriage, and an electric motor drive, shown in Figure 12. The track was constructed of pine lumber. A section 4.8 m (189 in) long and 3.8 x 23.5 cm (1-1/2 x 9-1/4 in) thickness and width lay flat to form the bottom of the channel. Two 3.8- x 13.0-cm (1-1/2- x 5-1/8-in) pieces 4.8 m (189 in) long were placed on edge and nailed to the top of the floor piece, thus forming the sides of the U-shape. The channel was 9.8 cm (3-7/8 in) wide and 13.0 cm (5-1/8 in) deep.

The plant carriage fit in the channel flush with the top edge and was 1.8 m (6 ft) long. Carriage halves were constructed of 1.9- x 13.0-cm (3/4- x 5-1/8-in) boards on edge. Both carriage sides which faced the inside channel walls were extended by nailing 1.9 cm (3/4 in) thick strips such that an end view of the carriage appeared as an I-shape.

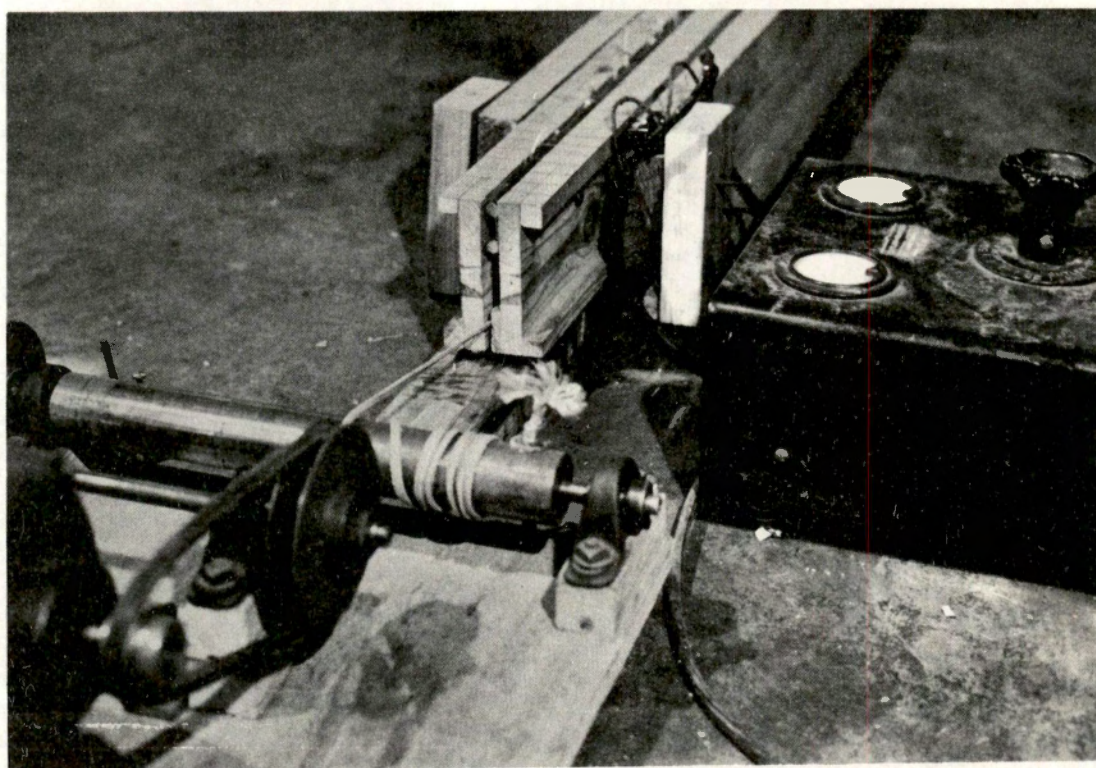


FIGURE 12. Plant carriage system for laboratory tests.

The carriage halves were connected by eleven 7.9 mm (5/16 in) carriage bolts 6.3 cm (2-1/2 in) long at 15.2-cm (6-in) intervals. One carriage half had two strips of foam type weatherstripping tacked to the inside, one near the top edge and one about 3.8 cm (1-1/2 in) from the top edge. The weatherstrips and short bolt spacing provided fairly uniform clamping of plants in the carriage. Plants could be clamped vertically but would slip in the carriage if a force was applied to the plant along the carriage axis. The overall carriage width without plants was approximately 8.6 cm (3-3/8 in).

The carriage was propelled by an electric drive system. A 0.25 kW (1/3 hp), 120V single phase electric motor provided power to a 4.8 cm (1-7/8 in) diameter, 35.6 cm (14 in) long steel roller through a speed reduction pulley system. Two variable pitch pulleys were used to vary the speed at which the roller turned. A motor control rheostat was used to vary the voltage input to the motor and allowed further speed variations. The roller was used to wind a strand of 0.6 cm (1/4 in) diameter nylon rope connected to the carriage. As the rope wound around the roller the carriage was pulled toward the blade at the speed dictated by the voltage and pulley settings. A limit switch at the motor end of the track stopped the motor when the carriage passed. The power system was mounted on a plywood base. A 3.8- x 14.0-cm (1-1/2- x 5-1/2-in) board connected the track and power system. This complete assembly could be moved along the floor for positioning beneath either header.

No trays were used for the collection of losses. An area approximately 6 x 7.5 m (20 x 25 ft) was cleared of objects except for the test equipment. Soybeans were removed from the area after each test.

A 53 x 43 x 18 cm (21 x 17 x 7 in) deep aluminum pan was used to hold the samples during hand threshing. A portable fan blew trash from the sample pan. Mass of the samples was determined using a 2610 g (5.75 lb) capacity triple beam balance. A strobe light was used to set the band blade speed by indicating the drive shaft speed.

D. Blade Selection

Only a limited number of stock band blades were available with a thickness of 0.51 mm (0.020 in). Therefore, only a few blades were considered for the tests. The objective in selection of a blade for these tests was to provide the fastest cut with the least amount of disturbance to the plant, preferably at a low cost. Blades with finer cutting elements would make more and smaller cuts in severing the plant. It was believed that this action would impart less energy and vibration to the severed stems and thus reduce shatter losses.

A diamond particle edged blade was available on custom order from Ebtec Metalbelt Corporation. The diamond particles provided a smooth fast cut. This blade had a long-edge life potential. It was also available in a variety of band materials. A high strength, long-lasting blade was available. However, prices for a complete blade exceeded 300 dollars.

Remington Arms Company provided information on a tungsten carbide "Grit-edge" blade. The edge would have a long life but the band material was pre-selected. The 0.51 mm (0.020 in) thick blades were designed for use on portable band saws with small wheels. It was, therefore, expected to wear well on the headers. Different grit or

particle sizes could be ordered. The grit would provide a smooth cut. Some concern was expressed that plant particles would lodge between the grit and reduce its cutting effectiveness. A welded blade would cost slightly above 100 dollars.

A V-toothed blade was available from Do-All Company. This blade had V-shaped teeth with no set. It was normally used to cut soft materials and left no kerf. The tooth pitch available was 0.18 cm (14 teeth per inch). The teeth provided no positive engagement with the plant material to be cut. This blade was relatively less expensive; a complete blade could be bought for 12 dollars.

Conventional toothed band blades were available from several companies. These blades had teeth which provided a positive engagement with the plants. The teeth had an alternate set and left a kerf in the material. The available number of tooth pitches was limited since most of the blades were wood cutting blades. The blades cost about eight dollars each.

Although the "Grit-edge" blade cost more, it was selected for use in the laboratory tests. The grit size selected was a medium grit.

E. Procedure for Shatter Tests

Soybean plots were planted with a grain drill for field tests. Pickett, Essex, and Mitchell varieties were planted to provide different maturity dates. However, only the Pickett variety was used in the laboratory tests. Whole plants, including roots, were pulled from the field and shaken lightly to remove the soil. The plants were stored in small piles near the test stand for at least 24 hours before the tests.

The building temperature remained fairly constant, and the soybean seeds maintained a moisture content near 11 percent.

Several groups of plants were cut by the abrasive blade to allow it to "break in." Some plant material did lodge in the finer spaces between tungsten-carbide particles. However, the spaces were not filled, and the blade still presented a good cutting edge. The carriage-track assembly was placed under the appropriate header with 3 m (10 ft) exposed and the remaining length extended under the header to allow the carriage to completely pass the blade before it stopped. The blade was 4.4 cm (1-3/4 in) above the top of the carriage.

Prior to each test, 24 plants were clamped into the carriage. They were spaced approximately 7.6 cm (3 in) apart. The roots were held by the weather stripping at a depth simulating that found in the field. After the carriage halves were joined the bolts were tightened by hand. The carriage was turned upright and placed in the track.

The carriage speed was then set according to previous calibrations. The appropriate voltage level was provided by the rheostat motor control. The variable pitch pulleys were adjusted to provide the necessary speed reduction. Slack was removed from the nylon rope to prevent jerking the carriage. Simulated ground speeds were 3.2, 4.3, 5.4, and 6.4 km/hr (2, 2-2/3, 3-1/3, and 4 mi/hr) for the band-blade header.

The combine engine was started and operated at full throttle. The band blade was started using the control box switch. The strobe light was adjusted to the proper frequency for the test. Voltage on the blade drive was adjusted to bring the drive shaft speed to the strobe frequency. As soon as blade speed was stabilized, the carriage was

started and plants were fed into the blade. The blade speeds were 460, 610, 760, and 910 m/min (1500, 2000, 2500, and 3000 ft/min).

The plants were cut by the blade, and most of them fell onto the sloping header platform. Some of the plants slid from the header platform. Since the reel was inoperative, these plants were considered harvested. Shatter loss was collected from the floor and from the space on the steel angle below the blade where the beans would sometimes remain. Shatter loss included both loose beans and pods. Occasionally stalks were thrown clear of the header platform by the blade action. These were also included in shatter loss.

The other loss category was the "uncut" loss. This group included both stubble and lodged loss. Beans in pods which were attached to the stubble left on the carriage were included. Plants which were pushed over and not cut were also a part of this category. The two loss categories and the harvested plants were placed in labeled paper bags and stored.

The conventional header tests were performed in a similar manner to the band blade tests. New knife sections were riveted to the conventional cutterbar near its center. The plants were fed into these new sections during the tests. The simulated ground speed was 6.4 km/hr (4 mi/hr). The blade speed for the conventional header was proportional to engine speed. At top engine speed the cutterbar operated at 330 cycles/min.

The contents of each sample bag was hand threshed in the aluminum tray. The fan was used to blow light trash out of the beans. After threshing, each sample was weighed and the weights (in grams) recorded.

Sample bags of each test were weighed at nearly the same time to prevent effects of moisture content changes. Data from the laboratory test are presented in Table 4 in Appendix A.

The data were analyzed in two steps. First, the orthogonal effects of blade speed and ground speed in linear, quadratic, and cubic terms were tested using the Analysis of Variance (ANOVA) and General Linear Model (GLM) procedures of the Statistical Analysis System (SAS). The program is shown in Appendix A. Only terms up to third order were included since four values each of blade speed and ground speed were used. The percents of shatter loss, uncut loss, and total loss were based upon the total weight of beans from each test. The calculated percents of losses are listed in Table 1. The significance of the effects of orthogonal components of blade speed and ground speed was indicated by the GLM results (Tables 5 through 7, Appendix A).

The second step in data analysis was a three-dimensional regression showing the effects of blade speed and ground speed in equation or response surface form. The significant orthogonal effects were included as blade speed-ground speed interaction effects in the GLM regression. The result was equations describing the three loss quantities in linear, quadratic, and cubic terms of blade speed and ground speed.

The equations were plotted using a Hewlett-Packard desk-top calculator and Model 9662A X-Y plotter. Three-dimensional plots were produced and were useful for visualizing the response surface. However, plots which resemble contour maps were probably more useful in determining the effectiveness of the new header. Contours of shatter, uncut, and total losses were plotted using the equations resulting from the

TABLE 1. Calculated values for percents of losses.

Observation	Date	Replication	Treatment	Blade Speed/1000 (Ft/Min)	Ground Speed (Mi/Hr)	Percent Loss	
						Shatter	"Uncut" Total
1	120877	2	1	2.0	2.00	32.3633	22.7797
2	120877	2	2	2.5	2.00	11.6044	0.8577
3	120877	2	3	1.5	2.00	24.8214	26.6964
4	120877	2	4	2.5	4.00	17.7532	9.4301
5	120877	2	5	2.0	3.33	6.8632	8.0421
6	120877	2	6	2.0	2.67	33.6707	3.8638
7	120877	2	7	1.5	2.67	13.8228	0.7089
8	120877	2	8	1.5	4.00	13.7090	8.0745
9	120877	2	9	1.5	3.33	14.6209	5.7394
10	120877	2	10	2.5	3.33	20.4235	3.1059
11	120877	2	11	3.0	3.33	5.4923	7.6200
12	120877	2	13	2.5	2.67	8.9561	0.0000
13	120877	2	14	2.0	4.00	3.0805	0.8736
14	120877	2	15	3.0	2.00	5.7782	0.5726
15	120877	2	16	3.0	2.67	6.1538	0.4196
16	120877	2	17	3.0	4.00	2.0648	0.6100
17	120977	3	1	3.0	3.33	14.0784	1.5294
18	120977	3	2	1.5	4.00	11.4715	3.1250
19	120977	3	3	1.5	3.33	9.6208	9.3014
20	120977	3	4	3.0	2.00	1.1724	0.1466
21	120977	3	5	1.5	2.00	12.2485	1.9669
22	120977	3	6	2.0	4.00	3.7291	6.3788
23	120977	3	7	1.5	2.67	12.8148	14.2731
24	120977	3	8	2.5	3.33	6.3021	0.1854
25	120977	3	9	2.5	4.00	10.0688	0.4420
26	120977	3	10	2.5	2.00	9.3308	5.0193
27	120977	3	11	2.0	2.00	20.3603	1.3100
28	120977	3	12	3.0	4.00	2.9412	1.0230
							55.1430
							12.4622
							51.5179
							27.1833
							14.9053
							37.5345
							14.5316
							21.7835
							20.3603
							23.5294
							13.1123
							8.9561
							3.9540
							6.3509
							6.5734
							2.6748
							15.6078
							14.5965
							18.9222
							1.3190
							14.2155
							10.1079
							27.0879
							6.4875
							10.5108
							14.3501
							21.6703
							3.9642

TABLE 1. (continued)

Observation	Date	Replication	Treatment	Blade Speed/1000 (Ft/Min)	Ground Speed (Mi/Hr)	Percent Loss	
						Shatter	"Uncut" Total
29	120977	3	13	2.5	2.67	12.2854	3.7017
30	120977	3	14	2.0	2.67	14.1152	1.8258
31	120977	3	16	2.0	3.33	4.0284	0.1777
32	120977	3	17	3.0	2.67	4.6063	0.3749
33	121477	4	1	2.0	4.00	12.9298	1.2380
34	121477	4	2	2.5	4.00	9.4772	0.5265
35	121477	4	3	2.0	2.00	27.0102	17.4689
36	121477	4	4	3.0	4.00	3.5235	0.1258
37	121477	4	5	2.5	2.67	10.0815	2.0367
38	121477	4	7	2.5	2.00	6.8939	0.0000
39	121477	4	8	2.5	3.33	5.0082	0.0411
40	121477	4	9	3.0	2.67	1.9648	10.5998
41	121477	4	10	1.5	2.67	2.7158	11.9787
42	121477	4	11	1.5	2.00	14.9568	11.8790
43	121477	4	12	3.0	2.00	1.5568	0.7784
44	121477	4	13	2.0	3.33	1.2669	0.2184
45	121477	4	14	2.0	2.67	9.0821	7.3337
46	121477	4	15	3.0	3.33	5.7521	0.3930
47	121477	4	16	1.5	3.33	5.1273	1.8676
48	121477	4	17	1.5	4.00	3.6765	2.4510
							15.9871
							15.9410
							4.2062
							4.9813
							14.1678
							10.0038
							44.4790
							3.6493
							12.1181
							6.8939
							5.0493
							12.5946
							14.6945
							26.8359
							2.3352
							1.4854
							16.4157
							6.1451
							6.9949
							6.1275

regressions. Dotted lines on the contour plots represented the averages of the conventional tests. Contours of lower value than the conventional header average indicated better performance in the new header.

F. Results of Laboratory Shatter Tests

The graphic results of the computer regression are shown in Figures 13 through 18. The coefficients of the equations which these figures represent are shown in Tables 8 through 10, Appendix A. The three-dimensional view of Figure 13 indicates the amount of shatter as a function of blade speed and ground speed. The pronounced "hump" near the lowest blade speed-ground speed combinations is probably due to the blade cutting action.

The abrasive grit on the blade did not positively engage the plant fibers. Rather, it depended upon a certain degree of normal force from the plant to cause the fibers to be carried to failure. The plants tended to act as cantilever beams. Their mass acted as a prop at the free end to resist their being pushed over at higher ground speeds. A slowly applied force could easily push a plant over. A more rapidly applied force caused plants to bow; the top and bottom of the plant moving relatively little at first while the middle moved with the blade. The latter condition loaded the blade with the necessary force to allow cutting. The former condition offered less resistance to motion and, therefore, slower cutting occurred. Some plants broke before being completely severed. The slower cutting apparently allowed the plants to absorb more energy from the blade than in faster cutting. At slower

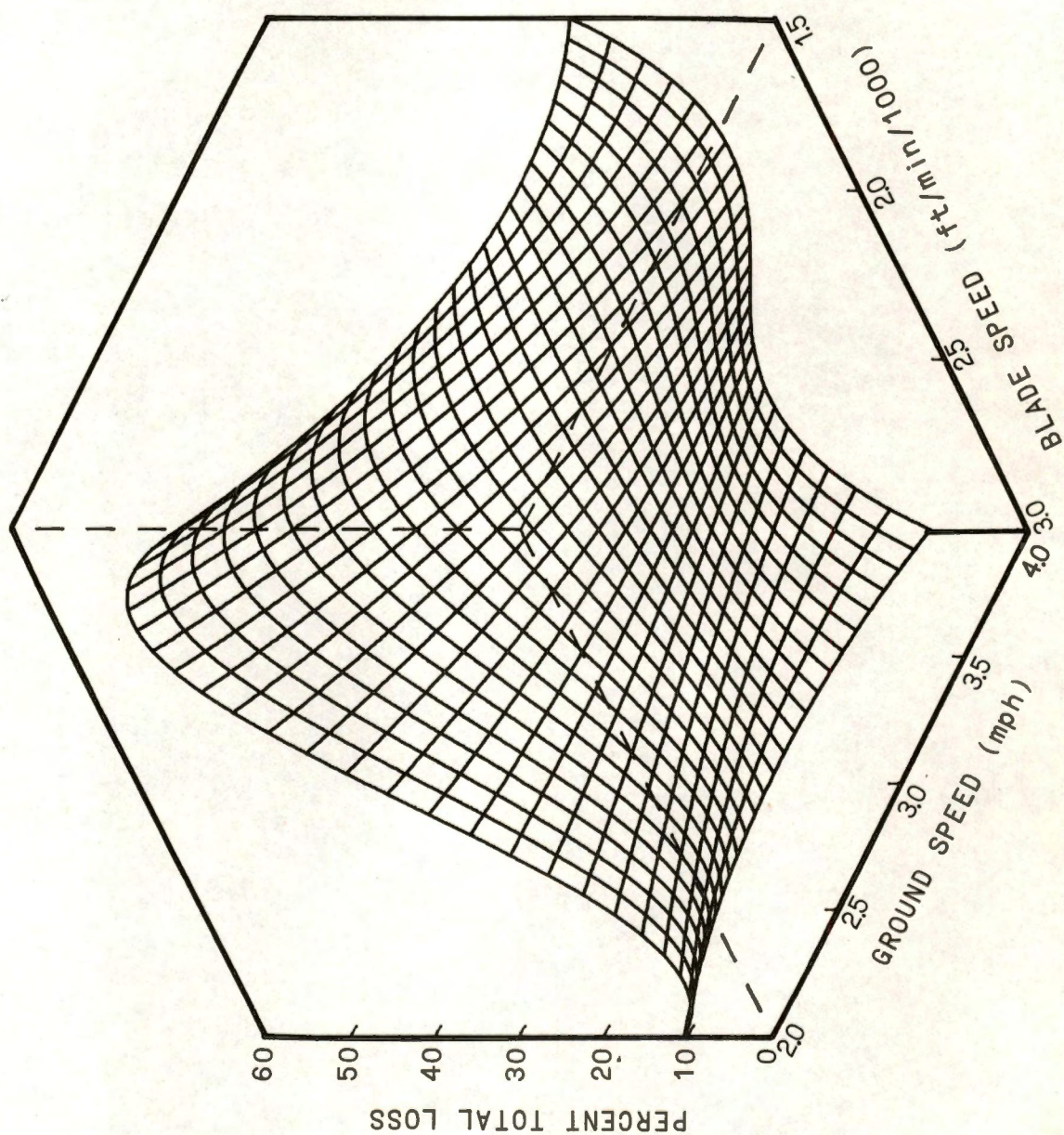


FIGURE 13. Percent shatter loss as a function of ground speed and blade speed.

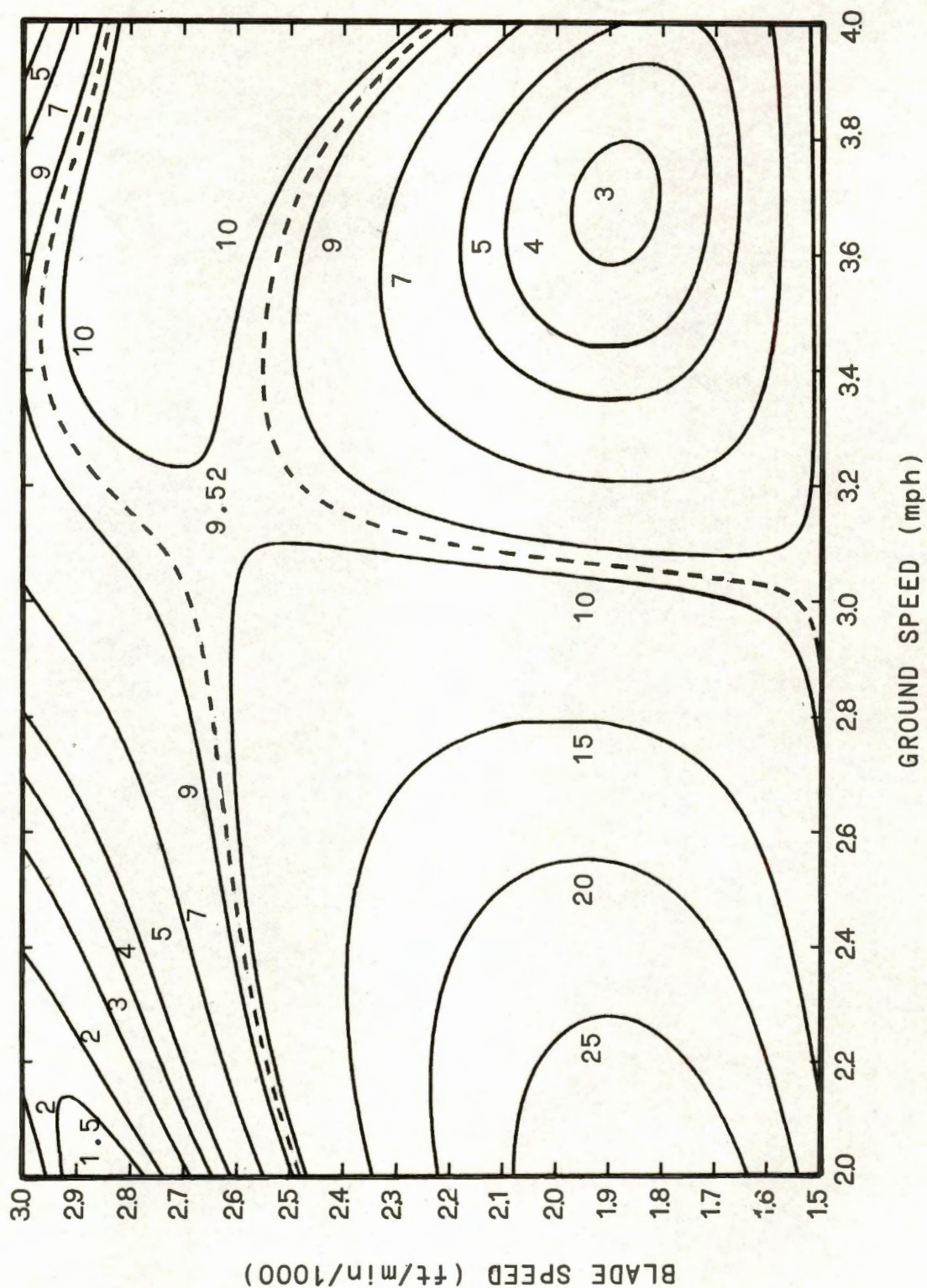


FIGURE 14. Shatter loss contours as a function of ground speed and blade speed.

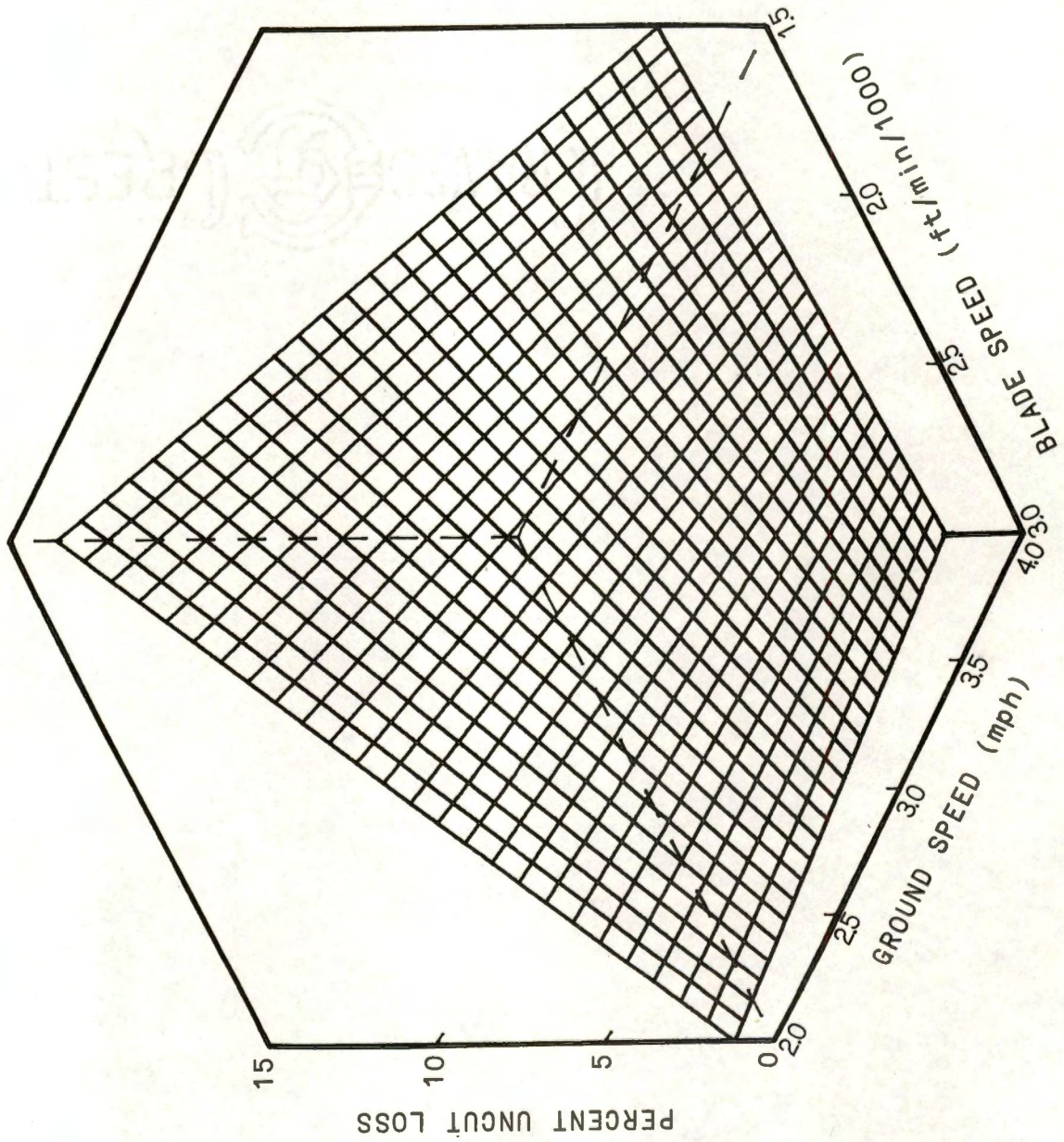


FIGURE 15. Percent uncut loss as a function of ground speed and blade speed.

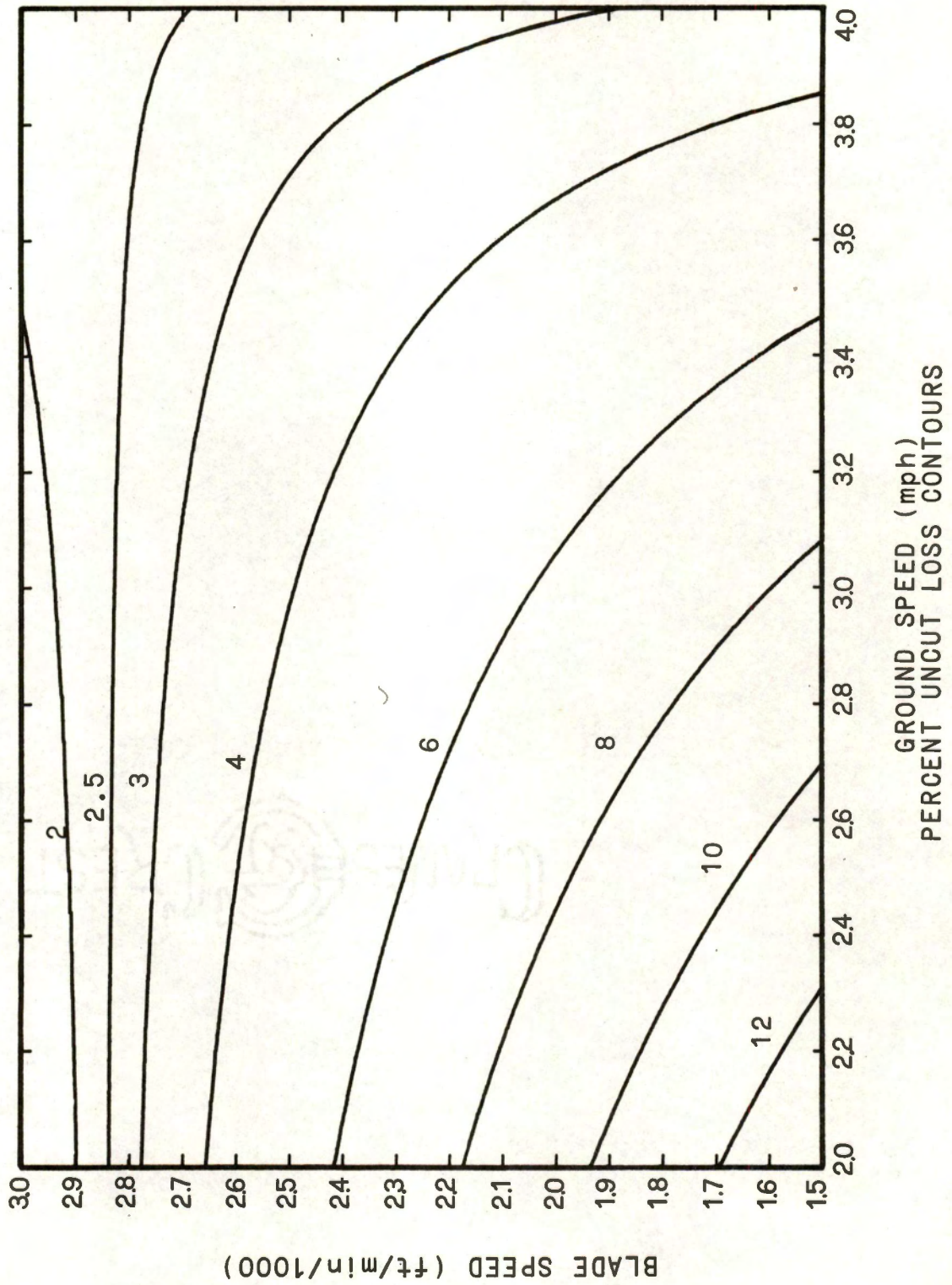


FIGURE 16. Uncut loss contours as a function of ground speed and blade speed.

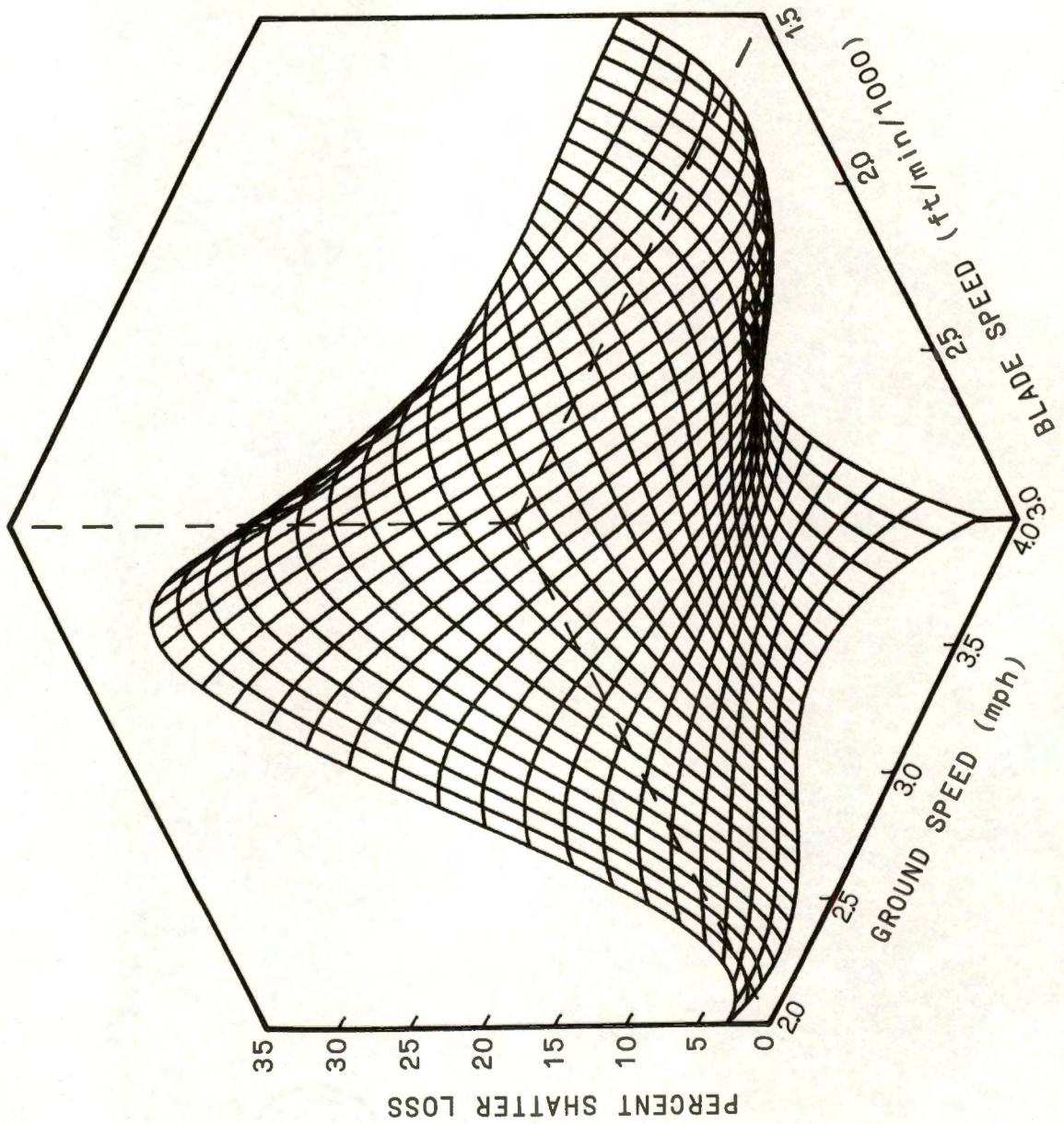


FIGURE 17. Percent total loss as a function of ground speed and blade speed.

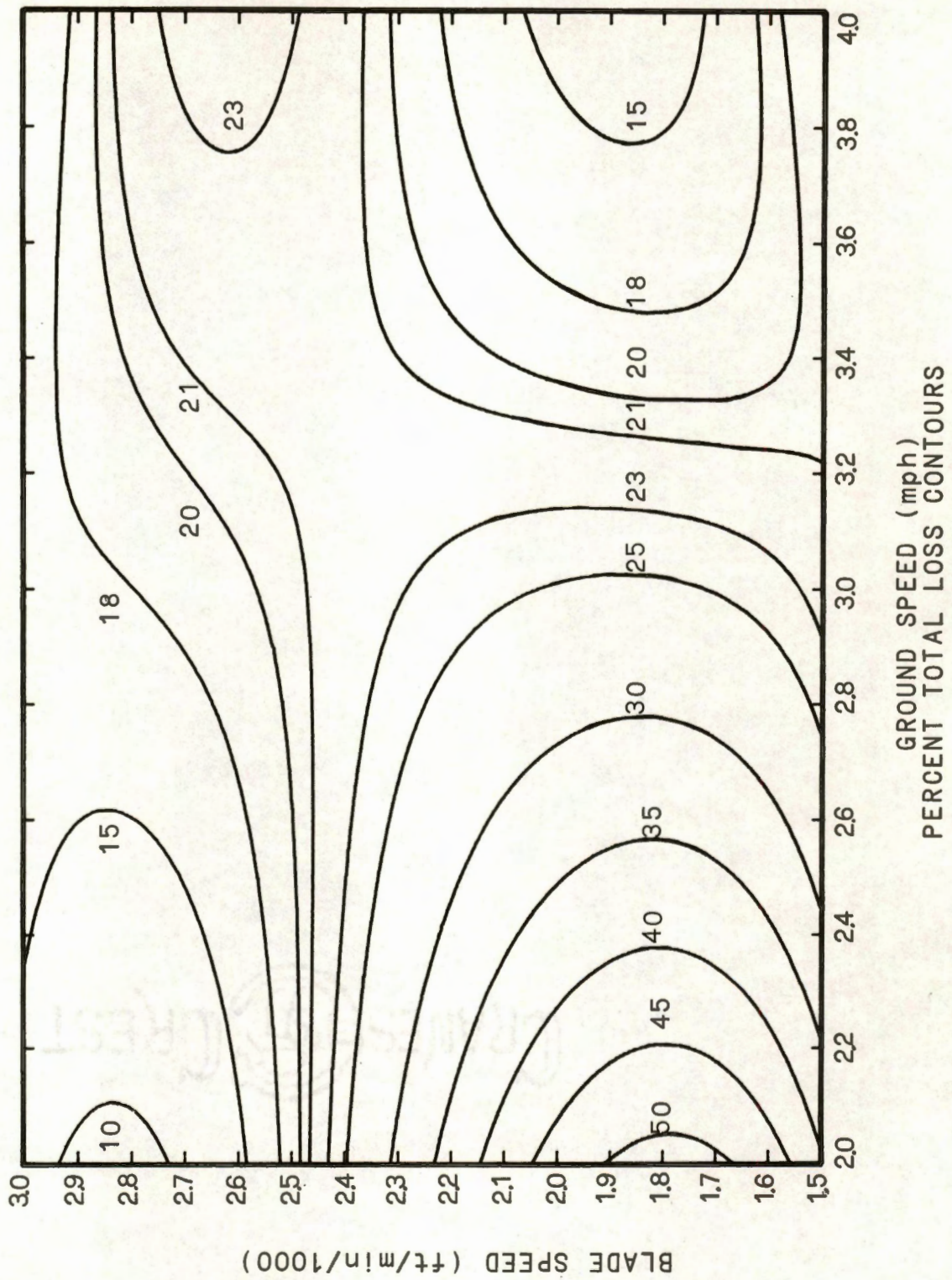


FIGURE 18. Total loss contours as a function of ground speed and blade speed.

blade speeds more plants were observed to travel transversely along the blade path after being cut. Some of these smashed violently against the platform wall, causing extra shatter. At higher blade speeds plants generally seemed to have less energy. Most tended to rotate and translate into the header fairly gently. Only slight motion of the plants was observed due to the transverse blade motion. The momentum of the plants tended to carry them (and some shattered beans) into the header after being cut. Thus, increasing blade speed and/or ground speed generally tended to reduce shatter caused by the abrasive blade.

Figure 14 is a contour representation of the equation describing shatter loss. The conventional header test was best represented as a horizontal plane passing through the response surface. The conventional shatter of 9.5 percent is shown in Figure 14 as a dotted contour. The figure indicates better performance of the new header for a blade speed of 910 m/min (3000 ft/min) over the range of ground speeds. The band blade performance was at least comparable to and sometimes better than the conventional blade at ground speeds greater than 4.8 km/hr (3 mi/hr) over the range of blade speeds.

Figure 15 is a three-dimensional representation of the percent "uncut" loss. This loss became essentially the lodged loss since very few beans were left on the stubble. As discussed earlier, the cutting action was slow for low blade speed-ground speed combinations. Plants, especially smaller ones, were easily pushed over with these conditions and were added to the uncut loss. This effect probably contributed to the shatter loss also since the blade tended to cut off parts of the plant as it was pushed over and the bottom of the header impacted the

stalk. The uncut loss also decreased substantially with increased ground and blade speeds. Figure 16, page 74, indicates the contours of percent uncut loss. The conventional average for this category was very low at 0.38 percent. The conventional blade was very effective at actual cutting and very few, if any, plants were pushed over. The band blade tested could not match this effectiveness.

Figure 17, page 75, is the three-dimensional presentation of the total percent loss of beans. This figure has characteristics of both loss categories as discussed earlier. Figure 18, page 76, shows the percent total loss contours. The conventional header had 9.90 percent total loss. The band blade did not have a lower total loss than the conventional header.

G. Photographic Studies

The cutting performance of the abrasive blade was observed using high speed photography. The films showed the cutting action in slow motion making possible comparisons of the plant reactions from the conventional and band blades.

Quick (1976) reported the use of high speed motion pictures to determine accelerations of plants and observe cutting. He tested conventional cutterbars, double shear cutting, and impact cutting. Soybean stalks or wood dowels were cut. Finite difference methods and Taylor's series expansion were used to find accelerations from the displacement on film. With X-Y coordinates in the film plane, Quick developed the accelerations for particles in that plane. The acceleration of a particle along the X-direction was

$$\ddot{x} = \frac{X(T+\Delta T) + X(T-\Delta T) - 2X(T)}{(\Delta T)^2}$$

where

$\ddot{x}$ = acceleration along the X axis,

$X(T+\Delta T)$ = displacement at time $T+\Delta T$,

$X(T-\Delta T)$ = displacement at time $T-\Delta T$,

$X(T)$ = displacement at time T , and

ΔT = real time increment between frames of the film being analyzed.

Acceleration along the y-axis took a similar form. Quick's calculations were performed by a rather lengthy computer program. He calculated acceleration accuracy to be near 10 percent.

Quick also used a stroboscopic still photograph method of studying plant response to cutting. This method involved time exposure of film during a sequence of strobe light flashes. The subject then appeared on the film each time the flash occurred. If the strobe frequency was known, acceleration could be found. This method was not as accurate as motion picture analysis. With self developing films, this method offered quick results on a single picture frame. Quick stated that the motion picture method was more suitable for cyclic motions.

Quick drew several conclusions from his observations. A bending mode vibration was seen in soybean plants near 2500 Hz. Shatter of pods was reported with accelerations approaching 300 g. Single impact cutting was observed to give the plants considerable energy and thus caused considerable shatter. He reported that all pods on a plant shattered in some cases of impact cutting. Multiple cuts (higher blade speeds)

reduced the shatter by reducing the energy transferred to the plants. He claimed that the initial impact of conventional blades did not usually cause shatter unless pods were directly contacted by the blade.

H. Photographic Equipment and Methods

The laboratory test stand described earlier was used in the photographic analysis. A Red Lake Hycam K2004 E camera was used with 30.5-m (100-ft) rolls of Kodak 16 mm 4X reversal film. Up to 4000 W of tungsten lighting was used in the tests. Both 100 mm and 50 mm focal length lenses were available. Light readings were taken with a Honeywell 1° spot meter.

Hyzer (1962) discussed the procedure for determining the camera frequency in high speed photography. The image blur on a 16 mm film frame should be less than 0.05 mm (0.002 in) to be acceptable. The blur was related to camera settings and characteristics as follows:

$$b = \frac{PWS \cos \theta}{\omega F}$$

where

b = image blur, in,

P = shutter duration/period ratio,

W = film frame width, in,

S = subject velocity, in/sec,

ω = field width seen by lens, in,

F = picture frequency, frames/sec, and

θ = angle between directions of motion and film plane, degrees.

For the Hycam equipment the duration/period ratio was 1/2.5. This quantity indicates the ratio of time the shutter actually stays open during the time for passage of one film frame. The 16 mm film frame width was 10 mm (0.4 in). The desired camera shutter frequency for the given equipment then was

$$F = \frac{PWS \cos \theta}{\omega b} = \frac{(0.4)^2 S \cos \theta}{0.002 \omega} = \frac{80S \cos \theta}{\omega}.$$

The proper equipment to perform a complete three-dimensional acceleration analysis was not available. Also, the camera lenses available had too long a focal length to provide an adequate field of view from an overhead position, perpendicular to both blade and plant carriage travel. The main interest was in studying the cutting action of the abrasive blade as compared to the conventional blade.

I. Photographic Procedures and Results

Two tests were performed on December 1, 1977, to give a general view of the cutting effects on plants and to gain experience with the equipment. The camera was set above and behind the blade for each test, such that the distance between the blade and the focal plane was approximately 4.9 m (16 ft). The camera, with 50-mm lens, was positioned 4.0 m (13 ft) behind the blade and at an elevation 3.0 m (10 ft) above the blade. Shutter speed for the conventional header test was 570 pictures per second (pps) for a blade motion of 330 cycles/min. For the band-blade header, shutter speed was 1778 pps for a blade speed of 760 m/min (2500 ft/min). These shutter speeds were found using the equation for shutter frequency. The field of view width was determined to be near

69 cm (27 in) after the camera was set up. The shutter speeds were sufficient to freeze the blade motion of the respective headers.

Light readings using the spot meter determined the lens diaphragm opening to be used. Uniform lighting of the plants as they entered the blade area was attempted. After camera settings were made and film was loaded, the appropriate blade and the plant carriage were started. Carriage speed was 5.4 km/hr (3-1/3 mi/hr). When the carriage passed a predetermined point the camera was started with a remote switch. Enough time was allowed for the camera to reach operating speed as indicated in the instruction manual. The plants were cut by the blade and the camera stopped automatically. A reversal process produced positive image film for viewing.

The films were studied using a variable speed motion analyzing projector. The films revealed a few general characteristics of the cutting actions. The conventional blade cut the plants very well, but the disturbance imparted by the oscillating blade was quite noticeable. Plants swayed from side to side as they approached the blade. A twisting motion was also noticed in some plants as they were cut; they appeared to rotate somewhat about a vertical axis during cutting. The band blade caused less disturbance in the standing crop than did the conventional blade. However, the plant rotated as the cut end was thrown in the direction of blade motion. The field of view was too wide to allow close-up study of the plants in these films.

Three additional tests were performed on December 12, 1977. The same procedure as before was used except that the camera was placed closer to the blade to give a close-up view of the plants. The field of

view was about 25 cm (10 in). The focal plane was 1.93 m (76 in) from the blades. The camera was 34.3 cm (13-1/2 in) behind the band blade and 43.2 cm (17 in) behind the conventional blade. All carriage speeds were 5.4 km/hr (3-1/3 mi/hr). Two films were made of the band blade header with band speeds of 910 m/min (3000 ft/min) and 610 m/min (2000 ft/min), respectively. The shutter frequency was 5000 pps for each. The conventional header film was exposed at 1500 pps.

From the film with the fastest band blade speed several observations were made. Plants moved into the blade and their momentum carried them onward except where the blade prevented motion. The plant bowed with top and base toward the header and was thus loaded similar to a spring. This caused a normal force on the blade by the plant sufficient to allow cutting by the rough blade edge. After the tests, some plants were found to have been cut as little as half way through and then had broken. The flexural loading of the plant caused it to fail after it had been weakened by the blade. The friction of the blade against the plant along the blade path caused motion of the cut end of the plant. This plant end sometimes gained sufficient energy to cause the plant to fly from view, rotating about its center of gravity as it did so. Other plants gained less energy and simply rotated and fell downward. Some twisting of the blade was seen, probably caused by the force of plants against its edge. This blade flexing implied that the normal force was relatively high. Pods were usually not disturbed excessively by the cutting action. Sometimes when the cut end accelerated rapidly, a few pods or beans would be lost near that end of the plant.

Some differences were observed at a blade speed of 610 m/min (2000 ft/min). The blade appeared to cut more slowly. Instead of springing forward over the blade during the initial blade contact, plant stems appeared to be pushed back by the force of the blade. This disturbed the pods somewhat more near the tip of the plant. Plant agitation was more noticeable in this film.

The film of conventional blade cutting showed that the first plant hit the blade knife before being cut. The plant top bowed toward the header and was pushed sideways by the blade. A whipping action resulted in shattered beans. An action not previously reported was also witnessed. Some of the plant stems were curved rather than upright and entered the header in various ways. As one of the curved plants entered the header with its convex side toward the header, the blade pushed the stem sideways. Since the blade force was not applied directly below the center of gravity of the stem, it caused a torque and therefore a rotation of the plant about a near vertical axis. The result of this rotation and sideways push was a violent whipping action at the tip of the plant which dislodged several beans. This could happen often in the field with lodged or leaning plants. A milder whipping action was also seen in which the plants were pushed sideways by the blade and then responded by whipping in the direction of blade motion.

J. Summary of Laboratory Results

Overall, the conventional blade cutting action was more violent than that of the band blade as viewed in the films. However, plants cut by the band blades seemed to gain more energy and, therefore, be

more subject to impact by other machine components. Cutting at higher band-blade speeds appeared to result in less disturbance of the plants, less energy imparted to plants, and less shatter. At lower blade speeds the grit edge would not cut into the plants fast enough to sever them before they were pushed over by the normal force. Cutting at higher ground speed tended to cause more of the flexural-type loading discussed earlier which provided higher normal force and ensured faster cutting. At lower ground speeds the plants did not have sufficient momentum to load the blade and aid cutting. Plants were pushed over before being cut under this condition. The tests showed that higher ground speeds and blade speeds improved performance of the abrasive blades.

Even though the "Grit-edge" blade had low levels of shatter for certain situations, the cutting action was not as desired. The blade did not cut sufficiently fast to penetrate plants before they "felt" the blade. Plants were sometimes pushed by the blade. Too much energy was transferred to the plants by the blade friction. Both of these factors caused shatter. A more aggressive cutting action was desired. The cutting action needed to be fast so that plants would be disturbed less.

CHAPTER V

ANALYSIS OF FIELD PERFORMANCE

A. Introduction

Field tests were performed in the fall of 1978. Field tests were deemed necessary to prove the feasibility of the band blade header as a means for gathering soybean plants.

Field testing, compared to laboratory testing, has some distinct advantages. Field operation provides a more realistic setting for header evaluation. Plants enter the header as they stand in the field. The effect of lodging becomes more apparent. Plants entering the header across its entire width have an effect on those plants already cut which is different from the effect of a single laboratory row. Adjacent plants in the field cling to each other and hold each other still. This action affects stalk and shatter losses. A larger sample of plants is available in the field. For these reasons the lesser degree of control exercisable in the field does not necessarily result in lower statistical reliability. Other advantages of field evaluation include more realistic blade wear and blade power requirements.

Several experimenters have performed field tests to evaluate combine headers. Dunn et al. (1973), Bichel et al. (1976), Nave et al. (1972), and others applied earlier defined field testing procedures with good results.

B. Improvements to the Header System

Several changes were made in the system between laboratory testing and field testing. The reel was modified to function satisfactorily. The old pivoting wood bats were replaced with pipe bars as discussed in Chapter III. The tine angles were adjusted by rotating the cam arms around the pipe bars. Preliminary field trials showed that an aggressive tine angle was required to properly convey the plants up the steep header floor. An angle of approximately 30 degrees rearward from vertical proved adequate. Also, the springs and cables which kept the reel chains tight caught lodged plants which resulted in a progressive buildup of plants as the combine proceeded through the field. The springs and cables were subsequently removed and replaced by a different tightening device. Two turnbuckles (threaded rod diameter of 1.3 cm (1/2 in)) were used to push the header frame downward from the combine main framework that held the upper reel sprockets. These turnbuckles not only provided faster and more positive chain tightening but also allowed easier blade changes. The reel chains and turnbuckles had to be disconnected when changing blades.

Removal of the reel tightening springs did not completely correct the plant buildup on the separators at each end of the header width. Plants still became tangled around the rods of the separators and around the blade guards. Two additional pairs of rods were welded to each separator at steeper angles to force lodged plants apart and prevent their accumulation. The extra rods helped but did not cure the situation.

As indicated from the laboratory tests, a higher blade speed was desirable. A new pulley was obtained for the blade drive shaft which would allow the blade to travel near 1830 m/min (6000 ft/min). Speeds between 460 m/min (1500 ft/min) and the maximum were obtained by interchanging blade drive pulleys and by adjusting the variable pitch pulley settings.

The laboratory tests showed need for a monitoring device which would indicate the blade speed. The strobe light used to measure blade speed in laboratory tests depended upon the line frequency for accuracy. A portable generator might not have a stable frequency. Also the blade speed decreased under load during the lab tests. A monitor with a continuous digital display mounted on the combine would tell the operator to compensate for the speed drop by raising the voltage supplied to the blade motor.

A Heathkit digital frequency/period meter, model IM-4110, formed the base around which the monitor system was constructed. This meter operated from rechargeable batteries for portable operation, from the 12 V combine battery, or from a 120 V line source. The meter range was between 5 Hz and 110 MHz. The meter counted electrical pulses in a signal and divided by the time period (crystal oscillator time base) to arrive at the frequency of the signal.

An optical method was selected to produce an oscillating signal from the rotating shafts of the blade drive. A light beam, interrupted by a toothed wheel mounted to the drive shaft where speed was to be monitored, activated a photo-transistor whose output was connected to the frequency meter. The photo-transistor (Motorola HEP P0003) was

slipped inside a black opaque tube, removed from a banana plug. Coaxial cable was soldered to the transistor. The assembly was taped to prevent the transistor and wire from sliding out. The opening through which light passed was approximately 0.5 cm (3/16 in) diameter. The photo-transistor was 0.6 mm (1/4 in) from the opening. The tube itself was only 2.5 cm (1 in) long and 0.95 cm (3/8 in) diameter. The other end of the coaxial wire terminated in a BNC connector. Three of these probes were constructed; however, only two were used in the combine tests.

A switching box was constructed to provide power to the probes and route the appropriate signal to the frequency meter. A 6 V lantern battery provided a constant voltage source for the probes. A single pole single throw switch controlled the battery power. A 0 to 5 K Ω potentiometer limited the amount of current in the signal from a probe and therefore adjusted it to match the sensitivity of the frequency meter. A three position rotary switch selected the probe to be monitored. The probes and a coaxial lead to the frequency meter were easily connected to the box. The circuit diagram is shown in Figure 19.

One probe each was mounted to monitor blade speed and combine ground speed. A twenty-tooth chain sprocket was mounted on the blade drive shaft. The probe was mounted close to the sprocket to allow the teeth to interrupt the light going into the probe. A 12 V light bulb was mounted opposite the probe opening. It was powered by the combine battery. Another probe was mounted in a similar manner in proximity to one of the ground drive sprockets. Calibrations were performed so that blade speed or ground speed could be determined from the meter. The system worked well during development. However, when it was mounted on

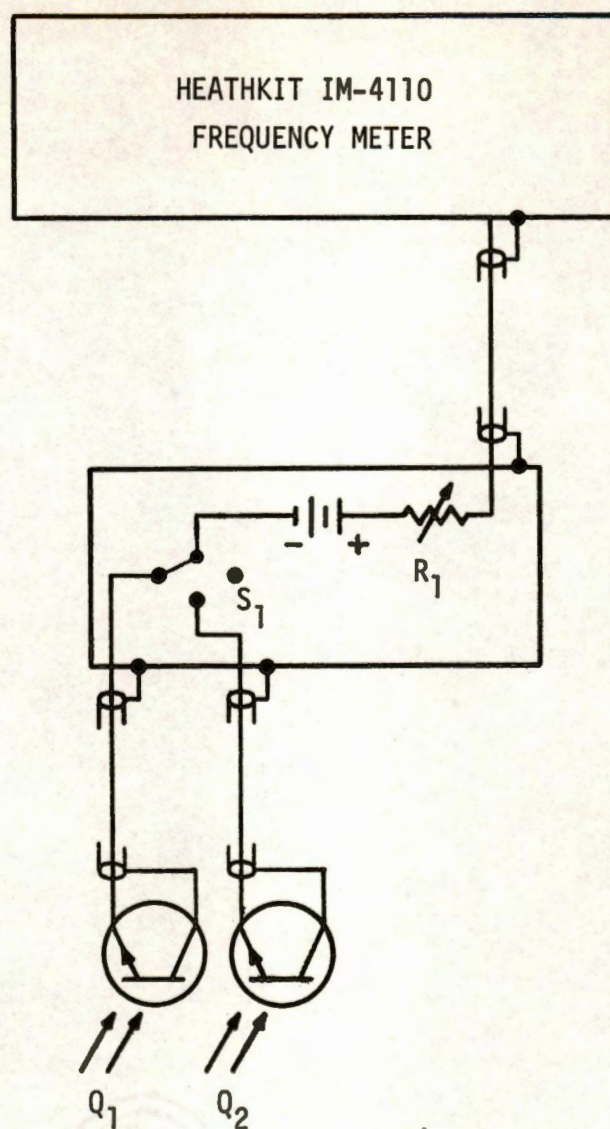


FIGURE 19. Circuit diagram of blade speed monitoring system.

the combine, the meter sensed the electrical noise from the engine and produced erroneous readings. An ignition noise suppression kit eliminated the noise except when the engine alternator was charging the battery at a high rate (during warm-up). The system performed well for field tests and, excluding the frequency meter, was relatively inexpensive.

C. Statistical Design

The effects of blade speed and ground speed were studied. The laboratory tests indicated that a fourth order equation would adequately relate these two variables to harvest losses. Therefore five levels each of blade speed and ground speed were selected for analysis in a factorial combination of treatments. Since shatter was known to be dependent upon moisture levels, the moisture content of the beans was monitored. The response variables were percents of shatter, lodged, stalk, and stubble loss. Two replications, completely randomized, were planned. Two tests of the conventional header provided a comparison for the new header. The experimental design then required 52 tests.

One bushel of Essex variety soybeans was planted for use in field tests. A grain drill planted the seeds in 17.8-cm (7-in) rows and thus approximated a broadcast crop. Plant spacing in rows averaged between 7 and 13 cm (3 and 5 in).

Preliminary tests of the new header prompted improvements to it as mentioned earlier. Several breakdowns of the header and combine occurred during the first few weeks of the harvesting season. Thus, several modifications of the combine itself were required before field

tests could begin. By the time these corrections were completed, rainy weather slowed the testing. As a result, several days separated the dates that tests were performed. Usually only six or seven tests could be done on one day. About 45 minutes were spent collecting the samples in the field for each test. Since tests were done between rainy periods, the bean moisture remained relatively high during the tests.

D. Blade Selection

Due to limited time and labor available, only one blade could be considered for use in the field tests. Of the blades discussed in Chapter IV, the diamond-edge blade was judged too expensive. The "Grit-edge" blade did not cut fast enough to sever plants before they were bent over by forward motion of the header. This deficiency was proven by the laboratory tests. It was also suspected that the grit would become filled with plant material during field use.

A V-toothed blade was tried on several plants in a temporary laboratory set-up. Several plants were clamped in the carriage used for laboratory tests and the operating header was driven over them. The cutting action observed was unsatisfactory. Small stems were severed but larger stems were pushed over by the blade. The teeth did not engage the plant fibers positively to carry them to failure.

A toothed wood-saw blade, made by Do-All, was tested similarly and was selected for use in the field tests. The teeth on this blade aggressively engaged the plant fibers. The cutting action was observed to be fast and smooth. The blade was not made of a fatigue-resistant material and thus had a short life expectancy, especially when used

with small diameter wheels. However, the blade was inexpensive compared to some other alternatives. The blade selected was standard spring steel, 0.51 mm (0.020 in) thick, 1.9 cm (0.75 in) wide, with a tooth pitch of 5.1 mm (5 per inch).

One such blade was used in testing the header before the experimental tests were begun. It was discarded after an estimated three hours of actual use just prior to the experimental tests. Cracks had begun to form at the roots of the teeth which indicated progressing fatigue failure. No visible wear on the teeth was observed.

E. Equipment

The instrumented combine and both headers were tested in field use. Four spare blades for the new header were available. An assortment of tools for maintenance and repairs were kept with the combine.

Loss samples were collected from a 137 x 91 cm (54 x 36 in) metal frame constructed from 1.3 cm (1/2 in) steel angle. Nave et al. (1973) used a similar frame which was 91 cm (3 ft) wide and reached the length of the cutterbar. They used only 30 cm (1 ft) of the width for collection of the shatter loss.

The mass of some samples was determined on a 7.5 kg electrically powered balance in the field. Power was supplied by a Black and Decker 2.5 kW portable generator.

Other equipment included an electric fan and aluminum tray for cleaning trash from beans. Wood stakes and steel tape were used to mark and measure the sample plot size. Paper bags were used to store the loss samples. Individual record sheets were prepared for each test.

F. Procedure

Tests were conducted in the plot of Essex variety soybeans. A uniform plot of plants was available which approximated a broadcast crop. Some large weeds were observed in scattered locations. The large weeds were avoided during selection of a test site. Before each test the selected plot was squared off at the point where the combine would enter. This point was marked by a wood stake. Approximately 3 m (10 ft) was paced off into the plot. This point also was marked by a wood stake and served as a target point near which the combine would be stopped.

The band blade speeds were set as noted previously by changing between the two pulleys available for the blade drive shaft and by adjusting the pitch of the variable pitch pulley on the drive unit. The band blade speeds were 610, 910, 1220, 1520, and 1830 m/min (2000, 3000, 4000, 5000, and 6000 ft/min). After speed selection, the engine was started and operated at full throttle. The frequency counter, battery power to the photo-transistors, and light sources were switched on. Then the belt clutch was engaged to start the various combine functions (header conveyor, fans, cylinder, shakers, etc.). The blade drive motor was switched on and the speed was monitored on the frequency counter. The voltage was adjusted to give the appropriate speed. Voltages ranged between 24 and 30 V at this stage. The voltage (and blade speed) tended to drop slightly under load. This was more noticeable at the faster blade speeds (higher torque) and ground speeds (higher load).

After the blade was started, the speed monitor was switched to the ground speed probe. The driver started the combine by moving the hydrostatic transmission control until the desired ground speed frequency was displayed. The ground speeds were 1.6, 2.4, 3.2, 4.0, and 4.8 km/hr (1.0, 1.5, 2.0, 2.5, and 3.0 mi/hr). An attempt was made to match the reel speed to the ground speed before the combine entered the plants. However, the hydraulic reel drive system was very hard to control and most often the reel ran too fast. As the combine approached the test plot a helper riding on the combine lowered the header to the ground. In wet soil the skids on the new header were hard to push. The header was raised slightly under these conditions to prevent stalling the combine or causing the wheels to spin. Still, the stubble height averaged 7.6 cm (3 in).

Near the second stake the forward motion was stopped. Power was removed from the band blade. As soon as the band motion stopped, the reel was stopped also. This was a safety measure to prevent workers from reaching into the blade area before the blade stopped (the reel was a more visible danger). The header was raised and any plants which had lodged on the plant separators were placed on the header conveyor belt. These plants were counted in the yield from the plot but were not counted in the loss collection. The conventional header had a similar lodged plant buildup problem which was treated in the same manner. Beans were observed flying from the cylinder area and landing on the ground, perhaps in the loss gathering area, during this period.

The combine was then backed from the test plot. The combine functions were left running until the shakers were clean and the clean

beans were collected in the cyclone separator on the combine. These beans were dumped in a paper bag then immediately cleaned and weighed. This sample later provided yield and moisture content information.

The distance from the first stake to the point where the blade stopped cutting was measured to the nearest inch with the 3.7 m (12 ft) steel tape. The loss frame was positioned in the plot area just in front of the combine wheel tracks. This avoided collection of losses in areas where the slowing combine speed or the wheel tracks would have an effect on the types or amount of losses found. Shatter (free beans or pods), stubble (pods attached to stubble), lodged (pushed over stems with pods attached), and stalk (lost, cut stalks) losses were collected in paper bags from the sample frame area. Any stalks which were only partially within the frame area were classified in a loss category but only the part within the frame was collected. Preharvest losses were recognizable due to their swelled moist condition caused by wet soil and were not collected. Many of the beans which shattered before harvest had sprouted due to the periods of alternately warm and wet weather which occurred between test dates. The loss samples, based upon the frame area, together with the harvested beans, based upon the total plot area, later gave percent loss information.

The conventional header was tested in a similar manner. The blade speed (approximately 330 cycles/min) was governed by the engine speed as mentioned in the previous chapter. The conventional header was tested at a speed of 3.2 km/hr (2.0 mi/hr).

All of the tests were conducted in the afternoon because of high bean and pod moisture before noon. Tests were necessarily conducted

between periods of wet weather. Therefore, the beans usually had a high level of moisture.

During the tests some observations were made about blade power. The power supply for the band drive system was monitored with a 0 to 50 A current meter and a 0- to 50-V volt-meter. During cutting the voltage remained near 24 V and the current varied between 45-50A. The power required then would be between 1080 and 1200 W (1.4 and 1.6 Hp). This power was at the maximum rating of the motor. The measurements were made at the maximum blade speed of 1830 m/min (6000 ft/min).

G. Data Reduction

The shatter, stalk, lodged, and stubble loss samples were hand shelled in the laboratory. They were dried in an oven at 75.6°C (168°F) for 24 hours. The mass was determined on a 200-g balance. The mass of the harvested beans was determined using a 7.5 kg balance. Two samples from the harvested bags were weighed, dried and then weighed again. These samples provided information on the total amount of dry matter in the harvested samples. The percent dry matter was determined as follows:

$$DM = 100 - \frac{W_{ws} - W_{ds}}{W_{ws}} \times 100$$

where

DM = percent dry matter, wet basis,

W_{ws} = mean weight of undried harvest bag samples, g, and

W_{ds} = mean dried weight of harvest bag samples, g.

The total weight of the harvested sample, had it all been dried would have been

$$W_{TD} = DM \times W_{TL} / 100$$

where

W_{TD} = total dry matter in harvested sample, g, and

W_{TL} = weight of harvested sample when drying samples were taken in the laboratory, g.

Then the moisture content of the harvested sample at harvest time was

$$M = \frac{W_{TW} - W_{TD}}{W_{TW}} \times 100$$

where

M = percent moisture content, wet basis, and

W_{TW} = weight of harvested sample in the field.

This procedure was necessary to reduce the large volume of beans to be dried from the harvested sample. The dried weights are given in Table 11, Appendix B.

The dried weights were adjusted for area to give a common basis for comparison. The losses were collected from the frame area. The harvested sample came from the strip cut by the header. Yield values were obtained in kg/ha units. The total yield was the sum of the yield of all losses collected and the harvested yield. The percent losses were calculated based upon the total yield:

$$L = \frac{Y_L}{Y_T}$$

where

L = percent of the particular type of loss to be found,

Y_L = yield from the loss sample, kg/ha, and

Y_T = total yield from all samples in the test, kg/ha.

The test data in final form are shown in Table 2. Information on blade speed, ground speed, date, moisture content, maturity, total yield and percent losses were all available for study. The maturity information consisted of an estimate, at harvest time, of the number of days passed since the beans were judged ready to harvest.

H. Data Analysis and Results

The data were analyzed using the Statistical Analysis System (SAS) on The University of Tennessee Computer Center facilities. The development of regression equations and response surfaces as in the laboratory tests was planned.

The General Linear Models Procedure (GLM) of SAS was used initially to obtain a general view of the effects of the independent variables on the types of soybean losses. Shatter, stalk, lodged, stubble and total losses (called SHR, STK, LOG, STB, and TOT, respectively, in the computer program) were considered as dependent variables in the model. The effects of ground speed (G), blade speed (B), ground speed-blade speed interaction (G*B), moisture (MOIST), date (DATE), and maturity (MAT) were included as independent effects. Ground speed, blade speed, and date were classified as discrete variables. Type I and Type III sums of squares (SS) were requested in the output. A model without maturity and one without maturity and moisture were also studied to indicate if an interaction of independent variables existed, especially among maturity and date.

The maturity effects were found to be confounded with those of the date. The use of both effects in the model was unnecessary. The

TABLE 2. Percents of field losses.

Date	Replication	Observation	Blade Speed/1000 (Ft/Min)	Ground Speed (Mi/Hr)	Yield (Kg/Ha)	Percent Loss				Maturity	Percent Moisture Content
						Shatter	Stalk	Lodged	Stubble	Total	
112078	1	1	5	1.0	3184	4.77	4.59	8.89	1.19	19.44	22.4
112078	1	2	6	1.0	3361	2.35	3.54	0.06	0.06	6.01	19.5
112078	1	3	5	3.0	3155	1.65	1.30	1.52	0.06	4.53	22.4
112078	2	4	4	1.0	2343	1.11	6.10	5.34	0.00	12.55	21.9
112078	1	5	6	1.5	3769	2.83	0.66	0.00	0.00	3.50	19.0
112078	2	6	6	2.5	1293	4.80	1.93	5.72	0.00	12.45	13.0
112278	1	7	3	1.5	3397	1.56	0.79	0.44	0.00	2.80	21.4
112278	1	8	4	3.0	2474	2.34	2.18	0.00	0.00	4.53	21.2
112278	2	9	3	3.0	2235	3.80	3.62	1.16	0.00	8.59	21.2
112278	1	10	4	2.5	2618	1.76	1.57	1.15	0.08	4.55	20.6
112278	2	11	3	2.0	2672	4.30	1.68	5.95	0.90	12.84	19.5
112278	2	12	4	1.5	2327	2.71	0.39	0.99	0.00	4.08	19.5
112278	1	13	6	2.0	1888	4.61	1.01	3.23	0.00	8.85	61
112578	1	14	2	1.5	3910	1.53	0.05	2.30	0.23	4.12	23.9
112578	2	16	5	2.0	3523	6.33	9.91	0.99	0.00	17.23	64
112578	2	17	5	2.5	3159	4.08	2.47	0.60	0.00	7.15	18.3
112578	1	18	5	2.0	2434	1.93	0.00	0.12	0.00	2.05	25.7
120178	1	19	2	3.0	2316	4.97	2.59	0.22	0.00	7.77	70
120278	2	20	2	3.0	2099	6.77	1.86	0.00	0.00	8.62	71
120178	1	21	2	1.0	3426	2.71	0.50	0.12	0.00	3.33	70
120278	2	22	5	3.0	2345	4.31	0.60	9.34	0.00	14.24	71
120278	2	23	3	2.5	2965	4.69	4.99	1.89	0.00	11.57	71
120278	1	24	3	3.0	1976	7.64	1.11	0.81	0.00	9.56	71
120278	2	25	5	2.5	2498	4.60	0.64	0.16	0.00	5.40	20.3
120178	1	27	6	3.0	2408	3.32	1.37	6.10	0.00	10.80	70
120178	2	28	4	2.5	3280	3.81	1.65	0.00	0.00	5.46	24.7
120678	1	29	2	1.5	2608	5.52	1.23	6.33	0.00	13.08	25.9
120278	2	30	2	2.5	1674	5.73	1.85	0.60	0.00	8.18	71
120278	2	31	5	1.5	2354	4.75	6.78	0.00	0.00	11.53	71
120678	1	32	3	2.5	2268	2.95	0.35	0.00	0.00	3.31	75
120678	1	33	6	2.5	2546	7.42	0.12	0.55	0.00	8.09	75
120678	2	34	6	2.0	2951	3.73	0.88	0.00	0.00	4.61	75
120278	2	35	2	2.0	2459	7.12	2.32	4.64	0.00	14.07	71
120678	2	36	6	1.5	2488	3.94	2.73	0.00	0.00	6.67	75
120678	2	37	4	3.0	2367	3.42	1.82	0.00	0.00	5.24	75
120178	1	38	3	1.5	2121	5.00	6.51	1.56	0.00	13.06	70
120678	2	39	5	1.0	2376	3.24	4.63	0.00	0.21	8.08	75
120678	2	40	6	3.0	1649	5.40	4.79	2.30	0.00	12.49	75
120678	1	41	5	1.5	2258	3.28	3.85	4.43	0.49	12.05	75
120678	1	42	2	2.5	2306	15.26	3.60	0.43	0.00	19.30	75
120678	1	43	3	2.0	2539	9.73	2.36	2.68	0.00	14.77	75
120278	2	44	4	2.0	2414	5.30	3.98	0.41	0.00	9.69	71
120278	2	45	3	1.0	2290	3.32	0.66	2.97	0.13	7.07	71
120678	1	46	4	2.0	2211	3.66	0.95	0.95	0.09	5.65	75
120678	1	47	4	1.0	3105	5.48	1.17	3.09	0.00	12.40	75
120678	2	48	2	1.0	2732	2.96	1.17	1.10	0.00	5.23	75
120678	1	49	2	2.0	2853	6.34	2.56	1.05	0.00	9.95	75
120678	1	50	6	1.0	2900	3.55	1.24	0.00	0.00	4.79	75
120678	1	51	3	1.0	2851	2.81	0.42	0.00	0.00	3.23	75
120678	1	52	4	1.5	2957	3.92	0.44	0.85	0.00	5.21	24.4

model containing all independent variables except maturity was considered the best model of the three. The computer output for this model is found in Tables 12 through 16, Appendix B. Ground speed effects on shatter losses were found significant at the 0.90 probability level. Moisture significantly affected stalk and lodged losses at the same probability level. No other factors were shown to have significant effects on soybean losses.

Since the ground speed effect was of interest and was shown to affect shatter losses it was studied further. Orthogonal contrasts of linear, quadratic, and cubic terms of ground speed were studied using the GLM procedure of SAS. The program and its output are given in Appendix B, and also in Table 17 of Appendix B, respectively. Only the effect of the linear component of ground speed was found to be significant at the 0.90 level of probability.

A linear regression of ground speed effects on shatter losses was performed using GLM. The program output is given in Table 18, Appendix B. The equation derived was

$$\text{SHR} = 2.675 + 0.854 G$$

where

SHR = percent shatter loss, and

G = ground speed, miles/hour.

Since the date of the tests was shown to have no effect on the results, the means of losses may be compared between the conventional and band blade headers. This was done using the Students'-T distribution.

The hypothesis was that the means of losses from the two headers were equal. Mathematically, the hypothesis, H_0 , is

$$H_0: \mu_1 = \mu_2$$

where

μ_1 = population mean for the conventional header, and

μ_2 = population mean for the band-blade header.

For the comparison of two means the value for T may be calculated from the equation

$$T = \frac{\bar{X}_1 - \bar{X}_2 - (\mu_1 - \mu_2)}{\sqrt{(N_1-1)S_1^2 + (N_2-1)S_2^2}} \quad \sqrt{\frac{N_1 N_2 (N_1 + N_2 - 2)}{N_1 + N_2}}$$

where

T = Student's- T value,

$\bar{X}_1$ = conventional sample mean,

$\bar{X}_2$ = band blade sample mean,

N_1 = number of conventional observations,

N_2 = number of band-blade observations,

S_1 = conventional standard deviation, and,

S_2 = band-blade standard deviation.

Since the population means were hypothesized to be equal, their difference was zero and they were not involved in the calculation. Table 3 illustrates the means, standard deviations, calculated T , and tabulated T values. The tabular T values were selected at the 95 percent level of probability for a two-tailed test (0.025 probability that a greater T magnitude exists). If the magnitude of the calculated T was greater than

TABLE 3. Comparison of harvest loss means using Students'-T test.

Loss Type	Band Blade			Conventional			Calculated T	Tabular $T_{0.025, 50DF}$	Hypothesis True?
	Mean	N	Standard Deviation	Mean	N	Standard Deviation			
Shatter	4.38	50	2.12	4.21	2	1.48	-0.112	-2.008	Yes
Stalk	2.32	50	2.01	6.40	2	8.00	2.472	2.008	No
Lodged	1.82	50	2.35	3.53	2	4.73	0.980	2.008	Yes
Stubble	0.07	50	0.21	0.47	2	0.66	2.434	2.008	No
Total	8.50	50	4.18	14.60	2	14.87	1.822	2.008	Yes

for the tabulated value at a certain probability and degree of freedom level, the hypothesis failed and the means were declared different. The tests had 50 degrees of freedom.

I. Discussion

All independent variable effects were not significant. Two possibilities exist which may explain the lack of significance of those variable effects which were expected to be significant.

First, it is possible that mean losses varied little over the range of blade speeds, ground speeds, and crop conditions tested. This implies that the header would provide near constant losses under various conditions, which would be a good characteristic if the average losses were low enough to be acceptable. Such performance would allow a slow blade speed without increasing the losses, thus increasing blade life.

The second possibility was that the field tests as designed were not sensitive enough to measure the difference in effects. Large standard deviations as compared to the means of losses indicated that more replication would offer improvement in test sensitivity. The field test design was based upon the laboratory test performance. Conditions were much harder to monitor and control in the field. More variation and therefore less reliability should have been anticipated in the field tests.

The effect of ground speed on shatter loss was as expected. Increased ground speed caused increased shatter loss and this effect was observed by other experimenters for conventional headers as discussed in Chapter II. This effect probably resulted from increased impact to the plants because of increased velocity of the header.

Increased shatter losses with plant maturity were shown to be significant by other experimenters. This effect was not significant in the tests reported here. However, the tests were performed over a period of just 17 days, possibly too short a period to reflect maturity effects. Replications extending over a full harvest season would provide a better measure of plant maturity influences.

Soybean moisture content, shown by other observers to be one of the most significant factors, was expected to affect the shatter loss. Low moisture content is known to have a definite effect on shatter loss; more shatter occurs when beans are dry. Due to weather, tests in drier conditions were not possible. The moisture levels ranged between 17 and 27 percent as measured in the field. Thus, a sizeable moisture effect on shatter loss did not occur.

The lack of blade speed effect on losses was surprising. The change in cutting action of the blade as its speed changed was expected to cause substantial changes in losses, especially shatter. The blade, however, was observed to cut plants very well at all speeds. The blade teeth apparently sawed through the plants very rapidly with little plant disturbance. Direct observation of the cutting action revealed that the plants gained less energy from the toothed blade than from the abrasive blade used in the laboratory tests. After being cut, the plants tended to have little motion. Usually only a slight rotation of the plant was observed. This fast, smooth cutting action should have reduced shatter.

The tests, as mentioned earlier, were not sensitive enough to measure the differences in shatter loss. Since the plants were as much

as 75 days past maturity and soybean moisture content was relatively high, blade speed effects were slight.

The comparison of means using the T tests indicated that the mean shatter, lodged, and total losses from the two headers were equal. The band blade as tested offered no decrease or increase in shatter losses. However, stalk and stubble losses were less when using the band blade header. This may be due to the effective cutting action and to the ability of the new header to cut close to the ground.

J. Recommended Header Changes

Several improvements to the header system are needed before further testing. The blade guides should be redesigned for use with narrower blades. The 1.3 cm (1/2 in) wide blades cut into the guide bearings at times. The bearings should be positioned to leave the blade teeth ahead of the bearing edge. Guards on the blade guides were inadequate. Plant stems often wedged lengthwise between the bearings. Sometimes the friction from such plants would slow the blade considerably.

Plants were also carried into the blade return protective housing. Some of these plants eventually passed between the blade and a band-wheel causing the blade to break or jump from the wheels. The plant buildup had to be removed periodically. The opening to the blade return housing needed to be much smaller to prevent the entrance of plants.

Finger-like guards along the length of the cutting surface might help lift some of the lodged plants and guide them to the blade. They might be designed to prevent unwanted objects from reaching the blade. These fingers could be combined with a shield to fit behind the blade

and prevent plants from slipping down behind the blade after being cut. Plants caught behind the blades were not always dislodged by the conveyor and reel. Plant buildups occurred as a result and interfered with smooth flow of material into the combine.

The plant separators on each side of the header should be redesigned. Possibly a longer, sharper form would lift the lodged plants before they became entangled around the blade framework and shields. A lodged plant would be pulled up by the roots rather than be separated from its neighbors, as was observed with both headers. These pulled plants usually started a plant pile-up on the separators. This situation may be very difficult to correct unless the reel can be designed to remove plants from the separators.

The reel should be redesigned. The present reel does not convey the plants adequately for satisfactory performance of the header. Plants cut by the band-blade tended to fall in an orderly fashion nearly parallel to the direction of travel. The reel tines would easily pass through the plants as more and more of them piled up. Eventually the reel lifted the plants to the conveyor and a mass of them were fed to the cylinder at one time. This "slug" of plants caused some problems due to lack of engine power. The tines should reach closer to the conveyor belt to engage the plants more effectively.

Some problems with the reel cam still exist. Sometimes the follower bearings attached to the bats were not caught by the cam and the bats were not guided properly. Also, the reel bats could flip over if the follower bearing reversed its travel in the radius of the cam. This situation was partially corrected by placing a spring tooth to

interfere with a tine on the reel bats such that the follower bearings were encouraged to continue their path around the cam radius. Occasionally a bat would flip over and sometimes carry plant material with it as it traveled around its circuit.

The reel also became stalled if a large weed or several plants became entangled in the sprockets and chains. A partial shield could be constructed to correct this problem, but the mechanism could not be completely enclosed.

If the blade framework were extended such that the blade return path was somewhat higher, the conventional reel could be used. The blade would be easier to change in this case. Reel position adjustments would be possible. A longer blade would have a longer life. However, the longer blade would also cost more.

The toothed blade cut well, but a better blade material would offer longer life. The spring steel showed signs of fatigue near the tooth roots after about three hours of testing. Breakage occurred most often when plant material was wedged between the blade and a wheel or when plant material pulled the blade from its guides as the combine was being backed from a test plot. Better shields as mentioned earlier would allow for a longer blade life. Alloy steel blades would be a wise choice of material. The "Grit-edge" blade used in laboratory tests showed little sign of fatigue and did not break. If spring steel blades are used, care should be taken to temper the welds properly to prevent brittleness and early failure.

The electronic monitor system could be improved. Noise in the signal from the engine and battery charging system tended to affect the

output, especially when the battery charge rate was high. Some type of filter system should be applied to the alternator to eliminate the problem.

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CHAPTER VI

SUMMARY AND CONCLUSIONS

A. Summary

For many years investigators have searched for a method of reducing the harvesting losses in soybeans. The conventional reciprocating cutterbar has been blamed for shattering soybeans from pods during cutting. Various improvements included cutterbar modifications, rotary impact cutting blades, rotary slicing blades, plant pullers, rollers or brushes to hold plants still, and others. Several of these devices were developed commercially. Unfortunately many of these improvements were not accepted by the farmer or just did not reduce grain losses substantially. Also, some of the more popular improvements were specialized row crop machines which limited them to certain row spacings and crops. A multi-purpose header which will adapt to the crop in either row or broadcast form is needed.

No record was found of research involving a band cutting element to harvest grain crops. A review of literature which described the cutting action of various devices prompted the selection of a band blade to reduce shatter losses in soybeans. The band blade should make many small cuts very rapidly and, therefore, not disturb plants excessively.

A header for use with a band blade was designed and constructed to attach to the Chain Machine Company SP-50 plot combine. The blade was

electrically-driven and traveled horizontally close to the ground, across the front of the new header. The blade returned around a rectangular path which had clearance for soybean plants beneath the returning blade. Four 20.3 cm (8 in) diameter band wheels were used to carry the blade. Stresses in the blade due to bending around the wheels dictated the use of blades having a 0.05 cm (0.020 in) thickness. The blade frame structure prevented use of a conventional reel. Therefore, a chain bat reel was constructed to perform the usual reel functions. The basic header framework was modeled after the conventional header supplied with the combine so that comparisons could be made.

Laboratory tests were conducted in the fall of 1977 in which the effects of band-blade speed and ground speed on losses of soybeans were studied. Plants were fed into the headers on a carriage system. An abrasive "Grit-edge" blade was used in these tests. The band was operated at speeds of 460, 610, 760, and 910 m/min (1500, 2000, 2500, and 3000 ft/min) and tested with ground speeds of 3.2, 4.3, 5.4, and 6.4 km/hr (2, 2-2/3, 3-1/3, and 4 mi/hr). Three tests were conducted with the conventional header having a simulated ground speed of 6.4 km/hr (4 mi/hr). The conventional cutterbar operated at 330 cycles/min. Shatter losses, "uncut" losses, and total losses were collected. Response surfaces of losses as affected by blade speed and ground speed were developed. Five high speed movies were made for study of the cutting action of both the band and conventional blades.

Field tests were conducted in the fall of 1978. A spring steel toothed band blade was used in these tests. The tooth pitch was 5.1 mm

(5 per inch). The new header was tested in two replications with all combinations of blade speeds of 610, 910, 1220, 1520, and 1830 m/min (2000, 3000, 4000, 5000 and 6000 ft/min) and ground speeds of 1.6, 2.4, 3.2, 4.0, and 4.8 km/hr (1.0, 1.5, 2.0, 2.5, and 3.0 mi/hr). Moisture and maturity of the beans were monitored. The conventional header was tested at a ground speed of 3.2 km/hr (2.0 mi/hr). The conventional header operated near 330 cycles/min. Response variables were shatter, stalk, lodged, stubble, and total losses. These were collected from the ground within a 137 x 91 cm (54 x 36 in) sample area.

B. Conclusions

The laboratory tests with an abrasive blade showed that shatter generally decreased as blade speed and ground speed increased. The abrasive edge provided a very smooth cutting action, but it did not cut rapidly enough. The plants were pushed by the blade before they were cut. Some of them broke before being cut completely through. Shatter loss was lower than in the conventional header at blade speeds of 910 m/min (3000 ft/min) over the range of ground speeds. The "uncut" losses and total losses were not lower than the conventional header.

The field tests with a toothed blade did not indicate a shatter reduction. The mean shatter, lodged, and total losses for the conventional and band blade headers were shown to be the same at the 95 percent level of probability. The means of stalk and stubble losses were shown to be less in the band-blade header than in the conventional header at the 95 percent level of probability. Blade speed, maturity, and moisture did not affect shatter losses. The linear component of

ground speed was found to affect shatter at the 90 percent level of probability. The toothed blade cut rapidly with little disturbance of the plants.

The band blade consumed about the same power as a conventional blade. Less than 1.1 kw (1.5 Hp) was generally required to drive the band blade at 1830 m/min (6000 ft/min).

C. Recommendations for Further Study

The band-blade header should be tested further to determine if shatter losses can be reduced. The field tests as done in this study were not sensitive enough to measure some effects. More replication of the band-blade header tests, together with testing of the conventional header over a range of ground speeds should be sufficient to provide more information. The improvements to the new header as listed in Chapter V are recommended.

The new tests should be planned to include a larger range of plant maturity. Moisture also should be considered over a larger range by performing tests in both dry and moist beans. The blade and ground speed ranges used in this study seemed to be appropriate.

Another area which deserves further study is that of blade characteristics. Which tooth pitch performs best? What blade materials have satisfactory fatigue life? Is the extra cost for better blade materials justified by the extra blade life? A high speed photographic study may help indicate the effects of blade tooth pitch. Some method of estimating blade life could be devised.

The band-blade header could offer an economic advantage to the farmer. This should be investigated. The band blade header might cost no more than the new commercial headers designed specifically for saving soybeans. These headers, having various methods and mechanisms for reducing shatter, are typically row-crop machines. This prevents the farmer from gaining the proven yield advantages of the broadcast crop. The band-blade header could harvest a broadcast crop as well as a row crop. Periodic blade replacement would be an economic disadvantage, however, if the blade materials were not properly selected for adequate blade life. Any economic analysis should be done only if significant reduction of losses can be consistently shown.



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APPENDICES



APPENDIX A

DATA, PROGRAMS, AND PROGRAM OUTPUT USED TO
ANALYZE LABORATORY DATA



TABLE 4. Raw laboratory data.

Date	Rep	Test	Blade Type	Blade Speed (Ft/Min)	Ground Speed (Mi/Hr)	Harvest Weight (G)	Shatter Weight (G)	"Uncut" Weight (G)
120877	2	01	R	2000	2.	89.4	64.5	45.4
120877	2	02	R	2500	2.	173.5	23.0	1.7
120877	2	03	R	1500	2.	108.6	55.6	59.8
120877	2	04	R	2500	4.	177.6	43.3	23.0
120877	2	05	R	2000	3.3333	202.1	16.3	19.1
120877	2	06	R	2000	2.6667	135.8	73.2	8.4
120877	2	07	R	1500	2.6667	168.8	27.3	1.4
120877	2	08	R	1500	4.	176.3	30.9	18.2
120877	2	09	R	1500	3.3333	190.1	34.9	13.7
120877	2	10	R	2500	3.3333	162.5	43.4	6.6
120877	2	11	R	3000	3.3333	175.6	11.1	15.4
120877	2	12	C		4.	172.9	26.5	0.7
120877	2	13	R	2500	2.6667	159.6	15.7	0.0
120877	2	14	R	2000	4.	208.9	6.7	1.9
120877	2	15	R	3000	2.	179.9	11.1	1.1
120877	2	16	R	3000	2.6667	200.4	13.2	0.9
120877	2	17	R	3000	4.	207.4	4.4	1.3
120977	3	01	R	3000	3.3333	215.2	35.9	3.9
120977	3	02	R	1500	4.	215.9	29.0	7.9
120977	3	03	R	1500	3.3333	203.1	24.1	23.3
120977	3	04	R	3000	2.	202.0	2.4	0.3
120977	3	05	R	1500	2.	191.9	27.4	4.4
120977	3	06	R	2000	4.	183.2	7.6	13.0
120977	3	07	R	1500	2.6667	165.0	29.0	32.3
120977	3	08	R	2500	3.3333	201.8	13.6	0.4
120977	3	09	R	2500	4.	182.2	20.5	0.9
120977	3	10	R	2500	2.	133.1	14.5	7.8
120977	3	11	R	2000	2.	143.5	37.3	2.4
120977	3	12	R	3000	4.	150.2	4.6	1.6
120977	3	13	R	2500	2.6667	156.6	22.9	6.9
120977	3	14	R	2000	2.6667	119.7	20.1	2.6
120977	3	15	C		4.	177.3	20.4	0.9
120977	3	16	R	2000	3.3333	161.7	6.8	0.3
120977	3	17	R	3000	2.6667	177.4	8.6	0.7
121477	4	01	R	2000	4.	187.2	28.2	2.7
121477	4	02	R	2500	4.	239.3	25.2	1.4
121477	4	03	R	2000	2.	196.1	95.4	61.7
121477	4	04	R	3000	4.	229.7	8.4	0.3

TABLE 4. (continued)

Date	Rep	Test	Blade Type	Blade Speed (Ft/Min)	Ground Speed (Mi/Hr)	Harvest Weight (G)	Shatter Weight (G)	"Uncut" Weight (G)
1214-7	4	05	R	2500	2.6667	172.6	19.8	4.0
121477	4	06	C		4.	165.2	8.8	0.6
121477	4	07	R	2500	2.	237.7	17.6	0.0
121477	4	08	R	2500	3.3333	231.3	12.2	0.1
121477	4	09	R	3000	2.6667	169.1	3.8	20.5
121477	4	10	R	1500	2.6667	175.9	5.6	24.7
121477	4	11	R	1500	2.	135.5	27.7	22.0
121477	4	12	R	3000	2.	213.3	3.4	1.7
121477	4	13	R	2000	3.3333	225.5	2.9	0.5
121477	4	14	R	2000	2.6667	172.1	18.7	15.1
121477	2	15	R	3000	3.3333	262.7	16.1	1.1
121477	4	16	R	1500	3.3333	273.9	15.1	5.5
121477	4	17	R	1500	4.	191.5	7.5	5.0

ORTHOGONAL COMPONENT ANALYSIS PROGRAM

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1  DATA ABRBLD;
2  INPUT DATE 1-6 REP 8 TMT 9-10 BLAD $ 11 B 13-16 G 18-21
3      HARV 26-30 SHAT 33-37 UNCT 40-44 ;
4  PCTSH=SHAT*100/(HARV+SHAT+UNCT);
5  PCTUN=UNCT*100/(HARV+SHAT+UNCT);
6  PLOSS=PCTSH+PCTUN;
7  BL=-3*(B=1500)-1*(B=2000)+1*(B=2500)+3*(B=3000);
8  BQ= 1*(B=1500)-1*(B=2000)-1*(B=2500)+1*(B=3000);
9  BC=-1*(B=1500)+3*(B=2000)-3*(B=2500)+1*(B=3000);
10 GL=-3*(G=2)-1*(G=2.67)+1*(G=3.33)+3*(G=4);
11 GQ= 1*(G=2)-1*(G=2.67)-1*(G=3.33)+1*(G=4);
12 GC=-1*(G=2)+3*(G=2.67)-3*(G=3.33)+1*(G=4);
13 LL=GL*BL;LQ=GL*BQ;LC=GL*BC;QQ=GQ*BQ;QL=GQ*BL;
14 QC=GQ*BC;CC=GC*BC;CL=GC*BL;CQ=GC*BQ;
15 DROP HARV SHAT UNCT BLAD ;
16 B=B/1000;
17 CARDS;

66  PROC PRINT;

67  PROC ANOVA; CLASSES G B REP;
68  MODEL PCTSH PCTUN PLOSS= G B G*B REP;

69  PROC GLM;CLASSES REP;
70  MODEL PCTSH PCTUN PLOSS=GL GQ GC BL BQ BC LL LQ LC QL QQ QC
      CL CQ CC REP;

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TABLE 5. Orthogonal effects of ground and blade speeds on percent shatter loss.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GL	1	266.07443619	11.52	0.0020	1	266.07443619	11.52	0.0020
GQ	1	23.61609991	1.02	0.3200	1	23.61609991	1.02	0.3200
GC	1	1.90520656	0.08	0.7759	1	1.90520656	0.08	0.7759
BL	1	359.85311657	15.58	0.0004	1	359.85311657	15.58	0.0004
BQ	1	216.72373783	9.39	0.0046	1	216.72373783	9.39	0.0046
BC	1	5.52740958	0.24	0.6282	1	5.52740958	0.24	0.6282
LL	1	208.32208824	9.02	0.0053	1	208.32208824	9.02	0.0053
LQ	1	80.55117769	3.49	0.0716	1	80.55117769	3.49	0.0716
LC	1	383.50281610	16.61	0.0003	1	383.50281610	16.61	0.0003
CL	1	103.87469702	4.50	0.0423	1	103.87469702	4.50	0.0423
QQ	1	20.49869290	0.89	0.3536	1	20.49869290	0.89	0.3536
QC	1	7.33382470	0.32	0.5772	1	7.33382470	0.32	0.5772
CL	1	10.00315541	0.43	0.5154	1	10.00315541	0.43	0.5154
CQ	1	85.63259861	3.71	0.0637	1	85.63259861	3.71	0.0637
CC	1	27.94849745	1.21	0.2800	1	27.94849745	1.21	0.2800
REP	2	333.49911724	7.22	0.0028	2	333.49911724	7.22	0.0028
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	PR > F	R-SQUARE	C.V.		
MODEL	17	2134.86667199	125.58039247	0.0001	0.755004	46.9415		
ERROR	30	692.75564789	23.09185493	STD DEV		PCTSH MEAN		
CORRECTED TOTAL	47	2827.62231989	4.80539852			10.23698961		

TABLE 6. Orthogonal effects of ground and blade speeds on percent uncut loss.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GL	1	141.72208303	4.76	0.0370	1	141.72208303	4.76	0.0370
GQ	1	16.84598722	0.57	0.4577	1	16.84598722	0.57	0.4577
GC	1	0.00948354	0.00	0.9859	1	0.00948354	0.00	0.9859
BL	1	298.75427012	10.04	0.0035	1	298.75427012	10.04	0.0035
BQ	1	13.43889627	0.45	0.5067	1	13.43889627	0.45	0.5067
9C	1	17.40105543	0.58	0.4504	1	17.40105543	0.58	0.4504
LL	1	122.83436407	4.13	0.0511	1	122.83436407	4.13	0.0511
LQ	1	0.00290797	0.00	0.9922	1	0.00290797	0.00	0.9922
LC	1	54.26672051	1.82	0.1870	1	54.26672051	1.82	0.1870
QL	1	46.28360186	1.56	0.2220	1	46.28360186	1.56	0.2220
QQ	1	38.78769747	1.30	0.2626	1	38.78769747	1.30	0.2626
QC	1	5.44294316	0.18	0.6719	1	5.44294316	0.18	0.6719
CL	1	1.24870690	0.04	0.8391	1	1.24870690	0.04	0.8391
CQ	1	1.15578896	0.04	0.8451	1	1.15578896	0.04	0.8451
CC	1	6.84129104	0.23	0.6351	1	6.84129104	0.23	0.6351
REP	2	75.42815643	1.27	0.2962	2	75.42815643	1.27	0.2962

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	17	840.46395399	49.43905612	1.66	0.1091	0.484932	119.4994
EPROP	30	892.69367834	29.75645594		STD DEV		PCTUN MEAN
CORRECTED TOTAL	47	1733.15763233			5.45494784		4.56483325

TABLE 7. Orthogonal effects of ground and blade speeds on percent total loss.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F	C.V.
GL	1	796.17068590	12.01	0.0016	1	796.17068590	12.01	0.0016	
GQ	1	80.35376633	1.21	0.2797	1	80.35376633	1.21	0.2797	
GC	1	2.18352543	0.03	0.8572	1	2.18352543	0.03	0.8572	
BL	1	1314.37458683	19.83	0.0001	1	1314.37458683	19.83	0.0001	
BQ	1	122.22695265	1.84	0.1846	1	122.22695265	1.84	0.1846	
BC	1	42.54302700	0.64	0.4294	1	42.54302700	0.64	0.4294	
LL	1	651.08839028	9.82	0.0038	1	651.08839028	9.82	0.0038	
LQ	1	81.52205413	1.23	0.2763	1	81.52205413	1.23	0.2763	
LC	1	726.29295084	10.96	0.0024	1	726.29295084	10.96	0.0024	
QL	1	288.83338850	4.36	0.0454	1	288.83338850	4.36	0.0454	
QQ	1	115.68132270	1.75	0.1965	1	115.68132270	1.75	0.1965	
QC	1	25.41284176	0.38	0.5405	1	25.41284176	0.38	0.5405	
CL	1	4.18333795	0.06	0.8034	1	4.18333795	0.06	0.8034	
CQ	1	66.89133131	1.01	0.3231	1	66.89133131	1.01	0.3231	
CC	1	7.13449567	0.11	0.7451	1	7.13449567	0.11	0.7451	
REP	2	660.58418752	4.98	0.0135	2	660.58418752	4.98	0.0135	
SOURCE		SUM OF SQUARES	MEAN SQUARE		F VALUE	R-SQUARE			
MODEL	17	4985.47684479	293.26334381		4.42	0.714857		55.0046	
ERROR	30	1988.61339814	66.28711327			0.0002		PLOSS MEAN	
CORRECTED TOTAL	47	6974.09024293				STD DEV		14.80182286	
						8.14168983			

TABLE 8. Regression coefficients of percent shatter loss vs. blade and ground speeds.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE IV SS	F VALUE	PR > F
REP	2	333.49911724	7.17	0.0028	333.49911724	7.17	0.0028
G	1	265.93682971	11.43	0.0020	18.17980816	0.78	0.3835
G*G	1	23.61609991	1.01	0.3215	49.75598638	2.14	0.1537
G*G*G	1	2.04281304	0.09	0.7690	69.39155387	2.98	0.0941
B	1	359.85311657	15.47	0.0004	1.72193570	0.07	0.7874
B*B	1	216.72373783	9.31	0.0046	16.46732197	0.71	0.4067
B*B*B	1	5.52740958	0.24	0.6294	46.63918356	2.00	0.1668
G*B	1	208.04613103	8.94	0.0054	7.59577808	0.33	0.5719
G*B*B	1	80.05241098	3.44	0.0732	0.13089331	0.01	0.9407
G*B*B*B	1	382.87781458	16.45	0.0003	21.49712904	0.92	0.3439
G*G*B	1	103.87469730	4.46	0.0428	45.21494000	1.94	0.1732
G*G*B*B	1	20.45869160	0.88	0.3552	20.47314445	0.88	0.3555
G*G*B*B*B	1	7.33381427	0.32	0.5786	7.33385036	0.32	0.5786
G*G*G*B	1	10.27910919	0.44	0.5112	79.53322433	3.42	0.0740
G*G*G*B*B	1	86.13134949	3.70	0.0636	86.13134949	3.70	0.0636

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > T	STD ERROR OF ESTIMATE
INTERCEPT	350.60056949	8	0.15	2357.50000403
REP	6.25966104	8	3.67	1.70545753
G	1.75941999	8	1.03	1.70545753
G*G	0.00000000	8	0.00	2134.72348691
G*G*G	-1886.90466961	8	-0.88	646.67915512
B	945.63955397	8	1.46	68.57196676
B*B	-118.41698944	8	-1.73	2836.38787163
B*B*B	771.59282803	8	0.27	1141.41438831
G*B	-960.21597803	8	-0.84	161.12124090
G*B*B	228.10897066	8	1.42	2348.81052402
G*G*B	1341.98671089	8	0.57	843.87529285
G*G*B*B	63.29233126	8	0.08	112.37060198
G*G*G*B	-108.00827655	8	-0.96	636.47691580
G*G*G*B*B	-887.23309561	8	-1.39	178.81812069
G*G*B*B*B	167.73276211	8	0.94	18.63599060
G*G*G*B*B*B	10.46243088	8	0.56	63.78117096
G*G*G*G	117.91821055	8	1.85	14.10411482
G*G*G*G*B	-27.13567054	8	-1.92	

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	PR > F	R-SQUARE	C.V.
MODEL	16	2106.29314233	131.64332140	0.0001	0.744899	47.1209
ERROR	31	721.32917756	23.26868315	STD DEV		PCTSH MEAN
CORRECTED TOTAL	47	2827.62231989		4.82376234		10.23698961

TABLE 9. Regression coefficients of percent uncut loss vs. blade and ground speeds.

SOURCE	DF	ESTIMATE	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
REP	2		75.42815643	1.45	0.2467	2	75.42815643	1.45	0.2467
G	1		141.71384224	5.44	0.0246	1	185.76776938	7.13	0.0107
B	1		298.75427012	11.47	0.0016	1	222.71527527	8.55	0.0056
G*B	1		122.90765034	4.72	0.0356	1	122.90765034	4.72	0.0356

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > T	STD ERROR OF ESTIMATE
INTERCEPT	47.22136788	3.71	0.0006	12.72711009
REP	1.90362475	1.05	0.2975	1.80471746
	-1.13470368	-0.63	0.5329	1.80471746
G	0.00000000	.	.	.
B	-10.95714967	-2.67	0.0107	4.10361514
G*B	-15.99561804	-2.92	0.0056	5.47117033
	3.84425895	2.17	0.0356	1.77001680

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	5	638.80391913	127.76078383	4.90	0.0013	0.368578	111.8225
ERROR	42	1094.35371320	26.05604079		STD DEV		PCTUN MEAN
CORRECTED TOTAL	47	1733.15763233			5.10451181		4.56483325

TABLE 10. Regression coefficients of percent total loss vs. blade and ground speeds.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
REP	1	533.11387910	8.43	0.0062	1	533.11387911	8.43	0.0062
G	1	795.91310862	12.59	0.0011	1	383.30522203	6.06	0.0186
G*G	1	80.35376633	1.27	0.2668	1	348.01188051	5.51	0.0244
B	1	1314.37458683	20.79	0.0001	1	760.65183182	12.03	0.0013
B*B	1	122.22695265	1.93	0.1727	1	798.13326767	12.63	0.0011
B*B*B	1	42.54302700	0.67	0.4173	1	768.37164878	12.15	0.0013
G*B	1	650.76911012	10.29	0.0028	1	655.12479567	10.36	0.0027
G*B*B	1	81.07841126	1.28	0.2647	1	748.31565966	11.84	0.0015
G*B*B*B	1	725.85412629	11.48	0.0017	1	725.85412692	11.48	0.0017
G*G*B	1	288.83338915	4.57	0.0392	1	288.83338915	4.57	0.0392

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > T	STD ERROR OF ESTIMATE
INTERCEPT	-1821.65801799	-3.06	0.0041	595.84573347
REP	-4.08164289	-2.90	0.0062	1.40553620
G	495.01272561	2.46	0.0186	201.03006780
G*G	25.06364277	2.35	0.0244	10.68228548
B	2910.58863991	3.47	0.0013	839.08294839
B*B	-1364.30586718	-3.55	0.0011	383.96449168
B*B*B	198.07078742	3.49	0.0013	56.81353148
G*B	-877.45507178	-3.22	0.0027	272.57115428
G*B*B	427.37942546	3.44	0.0015	124.21905398
G*B*B*B	-62.28114544	-3.39	0.0017	18.38014526
G*G*B	-9.84876150	-2.14	0.0392	4.60760187

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	10	4635.06035734	463.50603573	7.33	0.0001	0.664611	53.7158
ERROR	37	2339.02988559	63.21702393		STD DEV		PLOSS MEAN
CORRECTED TOTAL	47	6974.09024293			7.95091340		14.80182286



APPENDIX B

DATA, PROGRAMS, AND PROGRAM OUTPUT USED TO
ANALYZE FIELD DATA

TABLE 11. Dried weights of field samples.

Test	Replication	Blade Speed Ft/Min	Ground Speed Mi/Hr	Dry Weights, g				Wet Harvest Wgt (g)
				Shatter	Stalk	Lodged	Stubble	Harvest
1	1	5000	1	19.01	18.25	35.46	4.74	1646
2	2	6000	1	9.92	14.91	0.25	0.28	1458
3	1	5000	3	6.48	5.19	5.98	0.23	1325
4	2	4000	1	3.26	17.94	15.73	0.0	1036
5	1	6000	1.5	13.36	3.12	0.0	0.0	1782
6	2	6000	2.5	7.81	3.13	9.34	0.0	564
7	2	3000	1.5	6.67	3.35	1.86	0.0	1308
8	1	4000	3	7.28	6.80	0.0	0.0	835
9	2	3000	3	10.70	10.11	3.32	0.0	1024
10	1	4000	2.5	5.80	5.16	3.76	0.20	1036
11	2	3000	2	14.48	5.60	19.97	3.00	1445
12	2	4000	1.5	7.95	1.18	2.89	0.0	1417
13	1	6000	2	10.88	2.44	7.62	0.0	733
14	2	2000	1.5	7.49	0.23	11.28	1.07	1879
15	2	CONV	2	13.42	30.86	17.58	2.38	1002
16	2	5000	2	27.99	43.73	4.33	0.0	1503
17	1	5000	2.5	16.18	9.72	2.44	0.0	1874
18	1	5000	2	5.92	0.0	0.34	0.0	1100
19	1	2000	3	14.46	7.56	0.63	0.0	746
20	2	2000	3	17.75	4.85	0.0	0.0	790
21	1	2000	1	11.70	2.07	0.51	0.0	1651
22	2	5000	3	12.65	1.70	27.43	0.0	1125
23	2	3000	2.5	17.47	18.53	7.02	0.0	1277
24	1	3000	3	18.98	2.74	1.99	0.0	954
25	2	5000	2.5	14.38	2.00	0.52	0.0	1339
26	1	CONV	2	11.32	2.59	0.61	0.0	1713
27	1	6000	3	10.02	4.13	18.46	0.0	921
28	2	4000	2.5	15.62	6.78	0.0	0.0	1299

TABLE 12. GLM analysis of soybean snatter loss.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
G	4	42.20945200	2.37	0.0888	4	27.29917931	1.53	0.2325
B	4	36.51985200	2.05	0.1276	4	21.70803500	1.22	0.3354
G*B	16	72.71310800	1.02	0.4772	16	66.80600532	0.94	0.5464
MOIST	1	1.96296336	0.44	0.5145	1	4.07491650	0.92	0.3506
DATE	5	35.71978864	1.61	0.2066	5	35.71978864	1.61	0.2066

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	30	189.12516400	6.30417213	1.42	0.2154	0.691081	48.1330
ERROR	19	84.54034800	4.44949200		STD DEV		SHR MEAN
CORRECTED TOTAL	49	273.66551200			2.10938190		4.38240000

TABLE 13. GCM analysis of soybean stalk loss.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
G	4	3.82425200	0.24	0.9151	4	6.87709978	0.42	0.7903
B	4	18.66731200	1.16	0.3596	4	10.65896687	0.66	0.6305
G*B	16	76.86730800	1.18	0.3608	16	93.31511029	1.43	0.2249
MOIST	1	13.59742427	3.34	0.0832	1	5.26385514	1.29	0.2694
DATE	5	17.23076625	0.85	0.5334	5	17.23076625	0.85	0.5334

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	30	130.38706252	4.34623542	1.07	0.4497	0.627842	86.8071
ERROR	19	77.28805948	4.06779260		STD DEV		STK MEAN
CORRECTED TOTAL	49	207.67512200			2.01687694		2.32340000

TABLE 14. GLM analysis of soybean lodged loss.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
G	4	7.73314800	0.35	0.8414	4	10.29792843	0.46	0.7608
B	4	9.35918800	0.42	0.7905	4	6.30297686	0.28	0.8844
G*B	16	127.41193200	1.44	0.2232	16	134.15408467	1.51	0.1929
MOIST	1	17.58520318	3.17	0.0908	1	10.15117458	1.83	0.1917
DATE	5	14.01172771	0.51	0.7682	5	14.01172771	0.51	0.7682

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	30	176.10115889	5.87003996	1.06	0.4575	0.625916	129.2615
ERROR	19	105.24856911	5.53939837		STD DEV		LOG MEAN
CORRECTED TOTAL	49	281.34976800			2.35359265		1.82080000

TABLE 15. GLM analysis of soybean stubble loss.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F	C.V.
G	4	0.16698800	0.94	0.4607	4	0.12299107	0.69	0.6050	
R	4	0.25820800	1.46	0.2541	4	0.20351374	1.15	0.3639	
G*B	16	0.88893200	1.25	0.3152	16	0.74058180	1.05	0.4581	
MOIST	1	0.02784124	0.63	0.4376	1	0.02397348	0.54	0.4708	
DATE	5	0.18192120	0.82	0.5494	5	0.18192120	0.82	0.5494	
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	PR > F	R-SQUARE	C.V.			
MODEL	30	1.52389044	0.05079635	1.15	0.644316	305.8399			
ERROR	19	0.84123756	0.04427566	STD DEV		STB MEAN			
CORRECTED TOTAL	49	2.36512800		0.21041783		0.06880000			

TABLE 16. GLM analysis of soybean total loss.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
G	4	30.13689200	0.38	0.8169	4	24.31777430	0.31	0.8675
B	4	64.24391200	0.82	0.5284	4	26.21631890	0.33	0.8513
G*B	16	382.00768800	1.22	0.3369	16	405.85760408	1.29	0.2926
WLIST	1	44.13976010	2.25	0.1498	1	53.88866008	2.75	0.1136
CATE	5	56.42624184	0.58	0.7177	5	56.42624184	0.58	0.7177

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	PR > F	F VALUE	R-SQUARE	C.V.
MODEL	30	576.95449394	19.23181646	0.5300	0.98	0.607845	51.4944
EPROC	19	372.22514806	19.59079727	STD DEV			TOT MEAN
CORRECTED TOTAL	49	949.17964200		4.42614926			8.59540000

PROGRAM FOR ANALYSIS OF ORTHOGONAL GROUND SPEED
EFFECTS ON SHATTER LOSS

```
1  DATA A1978;
2  INPUT DATE 1-6 REP 8 TST 10-11 B 13-15 G 17-19 YIELD 21-24
   SHR 27-31
3  STK 33-37 LOG 39-43 STB 45-49 TOT 51-55 MAT 57-58 MOIST 60-63;
4  G=G*10;
5  CARDS;

56 PROC PRINT;

57 PROC GLM; CLASSES DATE G B;
58 MODEL SHR= G B G*B MOIST DATE/SS1 SS3;
59 CONTRAST 'GLIN' G -2 -1 0 1 2 ;
60 CONTRAST 'GQUAD' G 2 -1 -2 -1 2 ;
61 CONTRAST 'GCUBE' G -1 2 0 -2 1 ;
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TABLE 17. Orthogonal effects of ground speed on percent shatter loss.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
G	4	42.20945200	2.37	0.0888	4	27.29917931	1.53	0.2325
R	4	36.51585200	2.05	0.1276	4	21.70803500	1.22	0.3354
G*R	16	72.71310800	1.02	0.4772	16	66.80600532	0.94	0.5464
MOIST	1	1.96296336	0.44	0.5145	1	4.07491650	0.92	0.3506
DATE	5	35.71578864	1.61	0.2066	5	35.71978864	1.61	0.2066

CONTRAST	DF	SS	F VALUE	PR > F
GL IN	1	14.95136743	3.36	0.0825
GQUAD	1	7.80992613	1.76	0.2009
GCUBE	1	3.93630246	0.88	0.3587

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	30	189.12516400	6.30417213	1.42	0.2154	0.691081	48.1330
ERROR	19	84.54034800	4.44949200		STD DEV		SHR MEAN
CORRECTED TOTAL	49	273.66551200			2.10938190		4.38240000

TABLE 18. Regression coefficients of ground speed vs. percent shatter.

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
G	1	18.22436100	3.42	0.0704	1	18.22436100	3.42	0.0704
PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > T	STD ERROR OF ESTIMATE				
INTERCEPT	2.67480000	2.73	0.0088	0.97872586				
G	0.85380000	1.85	0.0704	0.46137580				
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	U.V.	
MODEL	1	18.22436100	18.22436100	3.42	0.0704	0.066594	52.6396	
ERROR	48	255.44115100	5.32169065		STD DEV		SHR MEAN	
CORRECTED TOTAL	49	273.66551200			2.30687898		4.38240000	

VITA

Joel Thomas Walker was born on August 15, 1953, in Knoxville, Tennessee. He attended Maynardville Elementary School and graduated from Horace Maynard High School, Maynardville, Tennessee, in 1971. He entered The University of Tennessee, Knoxville, in June, 1971, and received a Bachelor of Science degree in Agricultural Engineering in December, 1974.

He entered the Graduate School at The University of Tennessee, Knoxville, in January, 1975, and studied toward the Doctor of Philosophy degree in Agricultural Engineering. He served as a graduate research assistant until July, 1977, when he assumed the position of Instructor.

He is a member of the student branch of the American Society of Agricultural Engineers. He is also a member of the Honorary societies of Phi Kappa Phi and Gamma Sigma Delta.

He is married to the former Freda Lou Miracle of Pineville, Kentucky, and they have a son, Benjamin Eric.